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EVALUATION OF PROFILE DEVELOPMENT IN SOME
SOLONETZIC SOILS OF SOUTHCENTRAL ALBERTA

by



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A THESIS

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies for acceptance, a thesis entitled "Evaluation of Profile Development in Some Solonetzic Soils of Southcentral Alberta", submitted by Andre Brunelle, B. Sc., in partial fulfilment of the requirements for the degree of Master of Science.

ABSTRACT

Salt affected soils occur commonly in arid and semi-arid regions of the world. In the past fifty years, a large amount of work has been done on the evolution of Solonetzic soils. The purpose of this project was to investigate the translocation and transformation of clays upon solodization as well as to determine and compare the net clay gains or losses that have occurred in soils representing various stages of solodization.

Profiles representing different stages of solodization were sampled at three different sites in the Dark Brown zone of southcentral Alberta. Physical, chemical, and mineralogical analyses were conducted on the profiles sampled.

Profile characterization by chemical and physical analyses confirmed field classification of the soils studied. Disintegration of coarse material (sand size and coarser) into particles of finer diameter was evident in all profiles studied.

The electrical conductivity and soluble cations and anions in the soil water extracts suggested that within each sampling site the amount of soluble salt extracted from the soil profiles decreased with increased solodization.

Montmorillonite and illite accounted for more than 50 per cent of the total clay fraction. Preferential translocation of montmorillonite over illite was evident in all profiles studied.

Calculation of the net clay gains or losses occurring in each of the profiles studied revealed that for most profiles, the amount of clay gained by the illuvial horizons was larger than the amount lost



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from surface horizons. Such results suggested erosion of the surficial horizons and/or clay formation from the nonclay fraction.

On the basis of the investigation conducted, it was apparent that genesis, dissolution, transformation, and translocation of clay occurred as a result of solodization. Translocation of clays within the soil sola appeared the most evident.

It was evident from the evaluation of the net gains and losses of clay occurring in each profile that in situ clay genesis had occurred as a result of mineral dissolution. Illitization of montmorillonite was also found.

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INTRODUCTION

Salt affected soils occur commonly in arid and semi-arid regions of the world. Joffe (1949) reports that an estimated thirty-nine per cent of the world's dry land area is covered by saline soils. Bowser (1965) reports there is approximately 10 to 15 million acres of Solonetzic soils in Western Canada with a substantial acreage of Solonchaks, Solonetz, and Solods.

Three different processes are responsible for the formation of the various types of salt affected soils. These processes, referred to as salinization, solonization, and solodization will, if carried to completion, respectively lead to soils known as Solonchak, Solonetz, and Solod. Solodization, the third stage in the evolution of saline soils, is presented in this thesis with particular emphasis on its effect upon the clay size fraction.

In the past fifty years, a very large amount of work has been done on the evolution of Solonetzic soils. However, most of this work dealt with the relationship between the chemical status and morphological characteristics of Solonetzic soils as well as with the physiographic position and water regime peculiarities of these soils as compared to their zonal counterparts. Nearly all soil scientists who have studied solodization have reported depletion of clay in the eluvial horizon and presence of illuvial clay in the horizon of accumulation. However, it is not fully known whether or not the amount of clay accumulated is largely the result of illuviation, weathering in situ, or both of these processes.

Thus, the purpose of this project is to investigate the general mechanisms of solodization with particular emphasis upon the fate of clays. To achieve this purpose it is felt that the following objectives must be pursued:

- (1) To compare and relate morphological, physical, and chemical data of soils showing various degrees of solodization, but developed on relatively uniform parent material.
- (2) To reconstruct some solodized profiles according to a method outlined by Barshad (1964) and thus determine if net clay losses or gains occur upon solodization.
- (3) To determine the extent of clay losses or gains in soils representing various stages of solodization.
- (4) To study clay transformation and translocation in this sequence of solodized soils.

LITERATURE REVIEW

Morphological Characteristics of Solodized Soils

In this discussion, solodized soils indicate all soils fulfilling the requirements of the Solod Great Soil Group as defined by the National Soil Survey Committee of Canada (1965) in addition to subgroup members of the Solonetz Great Group showing clear signs of solodization. The two salient features of solodized soils are the presence of an eluvial horizon of variable thickness overlying an illuvial horizon having a columnar structure which gradually disintegrates, from the top down, as solodization progresses. As solodization proceeds, a transition horizon consists mainly of the upper part of the illuvial horizon which has gradually disintegrated. It is this feature that marks the division between Solonetz and Solod soils in the Canadian classification scheme.

The eluvial horizon (Ae) has usually a light grey color and platy structure (Joffe, 1949). As solodization progresses the A horizon becomes relatively thicker and the illuvial horizon relatively thinner (Bowser, 1965). Bentley and Rost (1947) and Bowser (1965) indicated that the individual platelets of the eluvial horizon are often darker colored on their lower surface. The greyish appearance of the Ae horizon of solodized soils is attributed to the presence of amorphous silica which Gedroiz, Paselov, and Antipov-Karatayev (Joffe, 1949) have associated to the solodization process.

The upper part of the illuvial horizon is generally rounded, occasionally flat, and generally covered with a white coating which extends downward into the spaces between the columns. Further

solodization results in disintegration of the round tops followed by gradual degradation of the upper columns as in the case in Solods. Vestiges of the upper portion of the columns may appear in the lower eluvial horizon (Mitchell, Moss and Clayton, 1944). White (1964) reported that solodized soils of a particular genetic environment show minor morphological features that can be related to chemical status while size and shape of columns are believed to be mainly related to soil texture and moisture regime. Solonetz soils of Alberta have columnar structure that vary from one to two inches to as much as a foot in diameter. The general biogeographical distribution of column size outlined by White (1964) is verified in Alberta soils.* White (1964) has associated the dome shape of the upper microcolumns to high permeability of the substratum or to short periods of very wet conditions. Stephens (Holmes and Stace, 1968) has attributed the domed structure of the upper portions of the columns to the expanding and shrinking properties of the sodium clays of the illuvial horizon under wet and dry conditions. It is possible to visualize conditions where vertical expansion would occur if horizontal swelling is limited by adjacent columns.

Holmes and Stace (1968) have found the columns of Solonetzic soils to be anisotropic and have attributed their domed structure to relatively greater swelling of the centre of the columns because of a larger amount of interstratified clays near the central vertical axis of the columns. Free ferric oxide and pH were also found to increase in the same manner while percentages of silt and quartz as well as the illite/kaolinite ratio decreased toward the centre of the columns. Regeneration

* Pawluk. Personal communication.

of illite at the periphery of the columns was postulated as an explanation for the changing illite/kaolinite ratio. The results tend to show the cylindrical symmetry of the columns. Retzer and Simonson (1941) have shown gradual increase in total carbon toward the centre of solonetzic macrocolumns. These data seem to indicate that a cross section of the upper portion of a given solonetzic column represents, to a certain extent, various degrees of solodization, the least solodized section being along the central vertical axis of the column. Higher amounts of interstratified clay material near the central vertical axis of the column may be attributed to diffusion of aluminum compounds produced by weathering of adjacent minerals.

Tursina (1966) has found the illuvial clay of Solods to be ferruginized and to occur as incrustations comprised of alternating layers of silt and clay, thereby demonstrating movement of silt and clay without prior decomposition. Illuvial clay of associated Solodized (crustal) Solonetz was somewhat less ferruginized. Greater ferrugination of the illuvial clay of Solods was attributed to greater variation in the redox-potential of these soils which causes greater amounts of iron to be solubilized, translocated, and concentrated. Podzolization occurring in the eluvial horizon of Solods, as stated by Duchaufour (1965) and Tursina (1966), may also contribute to clay ferruginization.

A characteristic feature of solodized soils is the heterogeneity of the moisture content throughout the profile. Tursina (1961) reports that the moisture content of the top horizon varies widely although generally lower moisture percentages are found in the centre of the profile. The upper illuvial horizon in view of its impermeability and

its shallow depth is thus subjected to a considerable number of wetting and drying cycles. It is believed that repeated wetting and drying of Na-saturated clays accelerates their rate of weathering. Helgeland (1968) showed that pure, homionic, sodium, and lithium saturated montmorillonites show much greater amounts of weathering than similar systems saturated with calcium or magnesium. The extent of weathering was measured by the amount of Al_2O_3 released into solution after given equilibration periods in distilled water or solutions of known composition. Helgeland (1968) indicated that Al_2O_3 is released from decomposing clay minerals as polymerized hydroxy ions and colloidal hydroxides. These products of weathering when in sufficient amount, were found to form a poorly crystallized "kaolin-type" mineral.

The upper portion of the solonetzic illuvial horizon because of its particular position with respect to moisture, cation saturation, and contact with organic acids is the site of the most intense weathering as evidenced by its clay mineralogy.

On the basis of the work cited above, it is evident that soil researchers have placed great emphasis upon the morphology of Solonetzic soils. It may be concluded that, generally, morphological characteristics of solodized soils can be related to chemical properties despite the unclear role of magnesium in the evolution of solonetzic soils.

Chemical Characteristics of Solodized Soils

Chemical characteristics of Solonchaks, to a large degree, reflect the characteristics of the salinizing waters. Upon removal of the soluble salts, Solonchaks may develop into zonal soils or acquire

solonetzic properties depending upon the kind of cations occupying the exchange complex. Salts present in Solonetzic soils vary greatly in their composition but NaCl , Na_2SO_4 , and NaHCO_3 usually predominate.

The National Soil Survey Committee of Canada (1965) has defined the solonetzic B horizon as an horizon "characterized by a columnar or prismatic macro structure that can be broken into a blocky meso-structure. The solonetzic horizon has a ratio of exchangeable calcium to exchangeable sodium of 10 or less." Bowser (1965) indicated that the most common salts in the soils of Western Canada are the sulfates of sodium, magnesium, potassium, and calcium. Carbonates, bicarbonates, and chlorides may also be present but are generally of lesser importance. Bowser (1965) suggested that solodization occurs at an early stage since the A horizons of Solonetz soils show slightly acidic reactions despite the fact that initial hydrolysis of sodium clays may be expected to result in an alkaline reaction.

The effect of exchangeable magnesium on solonetzic properties of soils has been studied by numerous workers. Buylov (1965) reported the work of Russian soil scientists such as Usov, Kovda, and Kaguchkov who claim that adsorbed magnesium is of no significance in conferring solonetzic properties to soils. However, most soil scientists concede the unusual behaviour of adsorbed magnesium. Bentley and Rost (1947), Ellis and Caldwell (1935), and Rost and Maehl (1943) reported the occurrence of Solonetzic soils having low amounts of exchangeable sodium and high quantities of exchangeable magnesium. Ehrlich (1958) reported the presence of some Solonetzic soils of Manitoba where adsorbed magnesium is believed to be the major factor of dispersion.

It must be pointed out, however, that adsorbed magnesium may not have directly contributed to solonetzic features of the soil. It is indeed possible to imagine conditions where magnesium salts would precipitate out as $\text{Mg}(\text{OH})_2$ at relatively alkaline pH (Riecken, 1943) and would thereby be in position to gradually occupy the exchange complex of a soil already having solonetzic features. Moreover, Horn, Rutledge, Dean, and Lawson (1964) have found that magnesium is held longer than sodium on the exchange complex. Magnesium precipitation as $\text{Mg}(\text{OH})_2$ does, however, depend on the composition of the salt solution and its pH. Garrel (Wilding, Odell, Fehrenbacher and Bavers (1963) pointed out the tendency of magnesium ion to form $\text{MgCO}_3 \cdot 3\text{H}_2\text{O}$ rather than MgCO_3 from saturated solutions of MgCO_3 . The hydrated form of the magnesium carbonate salt is much more soluble than MgCO_3 although less soluble than sodium carbonates and sulfates. Bowser, Milne, and Cairns (1962) have shown considerable overlapping in the amount of exchangeable magnesium found in soils of the Chernozemic and Solonetzic order. This last statement surely brings some doubt into the effective role of magnesium in determining solonetzic morphology. Uzakov (1961) reported the works of many authors who have correlated adsorbed magnesium to soil dispersion, reduced level of micro-aggregation, and compaction in the dry state. Joffe (1949) has found the properties of clay-adsorbed magnesium to be similar to sodium although less pronounced. Joffe and Zimmerman (1944) have found that for a given high percentage of adsorbed sodium, maximum dispersion is obtained when the ratio of adsorbed calcium over the adsorbed magnesium is wide. Minimum dispersion was obtained when the Ca:Mg ratio was narrow. It is unclear why high percentages of adsorbed

magnesium should reduce clay dispersion in the presence of large percentages of adsorbed sodium and increase it in the presence of lower percentages of adsorbed sodium.

Extent of solodization has also been correlated with the pH of the upper horizons of solodized profiles. Bowser (1962) reported that the pH of the Ah horizons usually increases from Solonetz to Solodized Solonetz to Solods and to Chernozems. Tursina (1961) has attributed the acid reaction of the upper horizon of Solods to the accumulation of acids resulting from the decomposition of organic residues. She further attributes reduction of the pH value to the formation of "available, complex, acid organo iron compounds." It is generally accepted that the acidity of solodized soils decreases from the eluvial horizon downward. Tursina (1961) has reported that the pH of the lower portion of the Solod profiles is closely related to fluctuation of the ground water level and to evaporation. The presence of vegetation on Solonetzic soils brings to the surface large amounts of calcium which is liberated upon plant decomposition. However, Joffe (1949) indicated that when no outside supply of bases is provided (aside from plant decomposition), solodization is accompanied by an acidification of the A horizon.

Topography and Solodized Soils

Many workers (Bentley and Rost, 1947; Joffe, 1943; and White, 1964) have attempted to correlate Solonetzic soils with a particular topographic position in a given physiographic environment. Since solodization is initiated after the removal of soluble salts, the balance between the amount of salt leached and the amount of salt

accumulated is dictated by the ground water regime which, in turn, may be related to the respective topographic position occupied by soils exhibiting variable degrees of solodization. In cases where the depth of the water table is sufficient to prevent any significant salt uplift by capillary movement, solodization may be expected to be well advanced. In cases where the salinizing effect of the parent material or ground water is strongly pronounced, solodization generally increases from the bottom toward the top of the slope. Arshad and Pawluk (1966a) carried out a study of Solonetzic and Black Chernozemic soils from the glacial Lake Edmonton basin and have associated the Solonetzic soils to ground water discharge areas where "the capillary rise from a permanently perched water table is sufficient to maintain a high salt level in the lower B horizon." Bentley and Rost (1947) have reported instances where the most solodized soils were not at the bottom of microslopes. Such cases were attributed to a higher water table favouring secondary salinization as suggested by Joffe (1949).

The results presented by Tursina (1961) indicate that the respective topographical positions of saline soils which present various degrees of solodization, depends upon the balance between the amount of salts lost by percolation at a given lower site and the greater proximity of this site to a salinizing water table. Fehrenbacher, Wilding, Odell, and Melsted (1963) have reported instances where the occurrence of Solonetzic soils was not related to surface microtopography nor to the microrelief of the underlying till. Wilding, Odell, Fehrenbacher, and Bavers (1963) stated that the source of sodium may not have to be external to the solonetzic soils area but can result from weathering "in situ" of

sodium bearing minerals with the added effect of differential redistribution of the products of weathering.

Wilding, Odell, Fehrenbacher, and Bavers (1963) have suggested the existence of local recharge areas where downward movement of salts takes place to a depth at which an increase in pH in the vicinity of calcite particles and a drop in the partial pressure of CO₂ results in the precipitation of calcium and magnesium carbonates. This chemical reaction results in an increase in the relative proportion of sodium in solution and therefore increases the relative rate of penetration of sodium on the exchange complex, thereby initiating clay dispersion. Horn, Rutledge, Dean, and Lawson (1964) have also pointed out the necessity of salt concentration in order to induce formation of Solonetzic soils. Hallsworth and Waring (1964) reported the occurrence of Solonetzic soils which at no time were Solonchaks but resulted from a mechanism of concentration of soluble salts. Thus, it may be concluded that "in situ" weathering of sodium and magnesium minerals would generally be insufficient to induce solonetzic soil formation unless mechanisms of redistribution are active.

Pedogenic Processes Involved in Solodization

It is well known that solodization does not start until the soluble salts are removed from the profile. As stated by Joffe (1949), "After the complete removal of soluble salts, hydrolysis sets in, and in combination with the acids produced in the process of humification, a replacement of some bases with hydrogen ions begins." Gedroiz (Joffe, 1949) indicated that solodization of carbonate-free Solonetz soils is accompanied by intensive decomposition of the alumino-silicate nucleus

of the absorption complex resulting in an accumulation of silica. Upon solodization, exchangeable sodium is replaced by hydrogen ion. This reaction is confirmed by the higher exchange acidity values of surface horizons of solodized soils as compared to their associated zonal soils. Data confirming the high exchange acidity of Solonetzic soils have been presented by Bowser, Milne, and Cairns (1962) and Bentley and Rost (1947).

Joffe (1949) attributed the peptization of organic and inorganic particles to the gradual removal of salts and to the saturation of the exchange complex with sodium and, to a lesser degree, magnesium. Peptization of organic and inorganic material results in downward movement of the colloids into the region of soluble electrolytes where flocculation occurs. Movement of organic and inorganic material in non-dissolved form has been confirmed by Tursina (1966). Accumulation of the translocated material causes the formation of an impervious layer. The dispersed state of the illuvial horizon will greatly reduce or prevent percolation. A change in the phases of the colloid system may then take place as a result of dispersion and water logging. Joffe (1949) postulated that the solid phase becomes the dispersed phase and the water becomes the dispersing medium. Weiser (1938) indicated that suspension of clay and clay-like substances may exhibit marked thixotropic behaviour under certain conditions. Bentonite was found to have thixotropic properties associated to the presence of adsorbed metallic cations. Weiser (1938) reported that suspensions containing as little as one per cent of natural bentonite are thixotropic provided that the largest particles are removed. Joffe (1949) stated that reversal of phases, occurring at the upper part of the illuvial horizon, under water logged

conditions increase reactivity of the constituents because of an increase of active surface. Weiser (1938) reported that alkali solutions favor thixotropy in most clays. From the above discussion, it seems possible that a very intense weathering occurs at the top of the illuvial horizon because of temporary and probably localized thixotropic clay masses. Indeed, the upper illuvial horizons satisfy all essential conditions required for the occurrence of thixotropy, namely abundance of fine material, water logged conditions, and existence of alkaline cations.

The upper illuvial horizon of some Solonetzic soils may also be characterized by the presence of sandy coatings of greyish appearance. Accumulation of silica can be readily observed in Solonetzic profiles showing some solodization. Pasilov and Antipov-Karatayev (Joffe, 1949) have related the presence of amorphous silica to solodization while accumulation of Al_2O_3 was attributed to podzolization. Basilevich (Joffe, 1949) does not consider the presence of amorphous silica as an indication of solodization but states that upward movement of alkali causes separation of silica. The role of silica in solodization must not be overlooked since Kubiena (1953) has reported silica sol as a possible agent involved in the translocation of iron oxides and clay minerals. Results of McKeague and Cline (1963(1)) seem to refute the postulated role of sol silica. These authors failed to find any significant amount of polymerized silica in soil water extracts, although the tendency of water soluble silica (monomeric) to be adsorbed on soil particles was shown. McKeague and Cline (1963) have subsequently shown that concentration of silica in soil solution is controlled by a pH dependent adsorption reaction. This adsorption mechanism cannot, in the opinion of the authors, account

for the presence of silica at the surface of Solonetzic B horizons. Silica may accumulate as the result of mineral weathering as indicated by Tursina (1966) who reported higher quartz/feldspar ratios in the eluvial horizon of solodized soils. The silica derived from weathering need not be in solution but can be in an amorphous form as stated by Joffe (1949) or adsorbed on soil materials (McKeague and Cline, 1963).

Solodization and Clays

The effect of weathering on clay minerals has been the subject of many papers. Barshad (1964) reported that under normal conditions, the weathering rate is slow and most of the products of weathering do not remain in solution. Joffe (1949) suggested that the reversal of phases of the colloidal system results in the solubilization of large amounts of organic and inorganic materials. Gedroiz (Joffe, 1949) reported that the solubility of organic matter from a Solonetz may be thirty-five times as high as in a Chernozem. Tursina (1960) associated the movement of clay to predominance of fulvic acids over humic acids in the composition of humus. Tursina (1961) stated that solodization occurs at the boundary of eluvial and illuvial horizons as a result of the alternate influence of mineralization by capillary waters and the leaching effect of percolating waters. The dispersed condition of the illuvial horizon also causes movement of fine particles into the B horizon. Arshad and Pawluk (1966b) and Gedroiz (Joffe, 1949) reported that a high content of exchangeable sodium in the Bnt horizon appears to cause comminution of coarse clay to finer particles. It is also generally accepted by soil scientists that the finer clay is more mobile than the coarser clay.

Barshad (1964) reported that clay generally involved in migration consists of particles of 0.1 micron or less in diameter.

Barshad (1964) reported that clay formation may result from weathering of primary minerals or from chemical combination of soluble weathering products present in soil solution. According to Barshad (1964), adsorption of calcium, magnesium, or sodium by mica causes the surface of this mineral to hydrate and to expand along the "c" axis. Such an expansion results in a crystal structure similar to that found in montmorillonite and vermiculite. Oxidation of iron contained in mica causes departure of potassium from the crystal lattice and its replacement by sodium, calcium, or magnesium. Such mechanisms are believed responsible for the formation of montmorillonite in alkaline media and vermiculite under more acidic conditions. Barshad (1964) reported that montmorillonite and vermiculite clays formed by weathering of mica contain larger amounts of aluminum in tetrahedral position than similar clays formed by combination of silica and aluminum hydroxides.

It may be postulated that the chemical conditions prevailing upon solodization at the upper portion of the illuvial horizon are conducive to formation of clay-like minerals similar to montmorillonite and vermiculite. This hypothesis seems possible in view of the relatively large concentration of alkaline earth cations as well as the intense weathering occurring at the upper part of the Bnt horizon. Barshad (1964) reported that diffusion of adsorbed H^+ into the crystal lattice for further interchange with tetrahedral aluminum or with octahedral aluminum and magnesium is responsible for converting mica-type structures to vermiculite-like minerals or vice versa. Jackson (1964) and Chernov

(1959) reported that exchangeable H^+ tends to react with layer silicates lattices to liberate octahedral cations.

All data pertaining to potassium status in solodized horizons indicates that potassium content decreases upon solodization and thus enhances the likelihood of vermiculite and montmorillonite formation by weathering of micas. Barshad (1964) reported that illite can also be formed by reduction in particle size of micaceous minerals as well as by condensation of hydroxylized aluminum compounds with polymerized silica. St. Arnaud and Mortland (1963) stated that fixation of potassium by expanding-type clay minerals results in an increase in illite. Holmes and Stace (1968) have also shown evidence of a process of "regeneration of illite" at the periphery of the columns of Solonchic soils.

There is ample evidence to suggest that chlorite also forms under conditions of severe weathering. Pawluk (1960) has identified chlorite-type minerals in B horizons of Podzols. Jackson (1964) indicated that polymerization of interlayer aluminum into larger units can occur in the vermiculite interlayer. According to Jackson (1964), soil acidity and chemical weathering of edges gradually prop open the layers of vermiculite and accumulation of interlayer material will occur until the vermiculite clay mineral effectively acquires all properties of chlorite. Blume (1964) has attributed the presence of chlorite in eluvial horizons of "sols lessives" of the Baltic Sea region to similar mechanisms. However, Jackson (1964) reports that, in acid environment, vermiculite can also weather progressively to montmorillonite while and after being interlayered. Harrison and Murray (1959) have suggested that transformation of chlorite can occur by development of expansible

layers within its structure. Such alteration would be attributed to the oxidation and removal of octahedral iron. This is in accordance with the results of Glass (1958) and Theisen, Webster, and Harward (1959), who related chlorite formation to conditions of intense weathering and good drainage where oxidation of iron is also favored. Chlorite is nevertheless very seldom mentioned as an important clay mineral of solodized soils. Glen et al. (Jackson, 1964) postulated that kaolinite may form from weathering of chlorite by tetrahedral inversion and splitting of the 2:2 mineral. However, there is no evidence to suggest that such transformation occurs to any significant extent upon solodization.

Barshad (1964) stated that clay formation may also occur by chemical reaction of products of weathering, namely hydroxylized aluminum compounds and soluble polymerized silica. According to this theory, the surfaces of clay minerals act as nuclei for adsorbing the silica and aluminum compounds. The adsorbed molecules become oriented in a "pattern similar or complementary to that of the substrate and condense through dehydration, into two dimensional sheets of linked tetrahedrons or octahedrons."

McKeague and Cline (1963) have failed to report the presence of any water-soluble polymerized silica in aqueous extracts of a wide variety of soils and have concluded that silica sol plays no dominant role in any soil genetic process. Nevertheless, clay formation by reaction of silica and aluminum compounds must be viewed with relative certainty since the rate of weathering is relatively slow and consequently the concentration or reaction products present in soil solution at any one time may be expected to be very low. Moreover, the weathering

products can be chelated by products of plant decomposition such as oxalates, citrates, tartrates, etc., and thus be concentrated in the illuvial horizon (Jackson, 1964) where they react to form clay or clay-like materials.

Barshad (1964) indicated that formation of montmorillonite is favoured in environments which have pH values greater than seven, high concentrations of calcium and magnesium, and have a $\text{SiO}_2/\text{Al}_2\text{O}_3$ and Fe_2O_3 ratio ranging from two to four. Similar environments but with high concentration of available potassium result in illite formation. The various horizons of Solonetzic profiles offer suitable conditions for clay weathering and clay genesis. Such conditions are: (a) presence of chelating agents favouring concentration of weathering products, (b) acidic pH, (c) fluctuating redox potential, (d) frequent wetting and drying of the upper illuvial horizon, and (e) presence of alkaline earth cations in lower horizons.

One of the striking features of solodized soils is the relative deepening of the eluvial horizon in contrast with a relative thinning of the illuvial horizon (Bowser, 1965). This phenomenon is confirmed by the occurrence of remnants of the illuvial horizon in the present A horizon. The relative decrease in thickness of the illuvial horizon upon solodization is believed to indicate either the possibility of a net loss of clay upon solodization or the eventuality of clay diffusion below the illuvial horizon in sufficiently low amounts that its detection becomes somewhat dubious.

Barshad (1964) has outlined a quantitative method for measuring soil development. This method is based on the assumption that soil

genesis results from chemical reactions in which the nonclay fraction represent the reactants and the clay fractions the products.

Determination of the degree of uniformity of the parent material is the first step involved in the evaluation of profile development. Assessment of the uniformity of a given parent material is done by evaluating the constancy, throughout the profile, of given minerals which are neither significantly weatherable nor likely to be translocated. Such minerals are termed "index minerals." Barshad (1964) suggested other means of assessment of parent material uniformity, such as total mineralogical analysis, nature of the particle size distribution of resistant minerals with depth, particle size distribution of the whole non-clay fraction, etc.

For soils developed from uniform parent material, the original amount of any kind of material (clay, sand, silt, etc.) present in any given horizon at the outset of pedogenesis can be correlated to the amount of index mineral present in the horizon studied. From the physical and chemical data obtained by the analysis of pedogenic horizons, the amount of clay gained or lost during soil genesis can be calculated. One of the main assumptions is that the amount of clay formed is proportional to the loss in the non-clay fraction. A proportionality factor is used in the calculation of clays formed since some material lost by the non-clay fraction will not enter into the synthesis of clay. One such material is the carbonate ion. The proportionality factor is introduced into the calculations by expressing the non-clay fraction as an entity apart from substances not involved in clay formation.

The method, as outlined by Barshad (1964), allows the

calculation of the amount of clay formed and lost either by translocation or weathering for each horizon. Moreover, the net amount of clay gained or lost by the profile during its formation can also be calculated.

In conclusion, this method affords a quantitative measurement of some of the chemical and physical transformations resulting from pedogenesis.

SUMMARY OF LITERATURE REVIEW

Salt affected soils are known to commonly occur in arid and semi-arid regions of the world. These soils have morphological characteristics that express their degree of evolution. Solonchaks are generally structureless soils while slightly solodized soils exhibit horizons that have a distinct morphology. The morphology of the illuvial horizon of Solonetz soils is characterized by columns that generally have rounded but sometimes flat tops. Continuous solodization results in the disintegration of the columns followed by gradual degradation of the rounded tops. Such soils are referred to as Solods. Investigations of Holmes and Stace (1968) and Retzer and Simonson (1941) indicate that the columns of Solonetzic soils are anisotropic and have cylindrical symmetry.

The upper portion of the illuvial horizon, because of its particular position with respect to moisture, cation saturation and contact with organic acids, is the site of the most intense weathering.

Solonetzic features have been invariably related to the presence of adsorbed sodium on the exchange complex. Adsorbed magnesium is believed to confer properties similar to those attributed to adsorbed sodium. However, Buylov (1965) reports on the investigations of several Russian soil scientists who claim that adsorbed magnesium is of no significance in the development of solonetzic characteristics.

For a given physiographic environment, Solonetzic soils of variable degree of solodization can be correlated with their particular topographic position. The respective topographic position of saline

soils presenting various degree of solodization depends upon the balance between the amount of salt lost by percolation at a given site and the proximity of this site to a salinizing water table or parent material where the salts are maintained as a result of ground water discharge.

Joffe (1949) reports that solodization does not start until the soluble salts are removed from the profile. Joffe (1949) reported that one of the main features of solodization is the replacement of adsorbed sodium by hydrogen ions produced in the process of humification. Solodization is also accompanied by peptization of organic and inorganic materials and their translocation, from the eluvial horizon, to the illuvial horizon where they accumulate.

The dispersed state of the upper illuvial horizon greatly reduces or prevents percolation. A change in the phases of the colloidal system may then take place as a result of dispersion and water logging. Joffe (1949) postulated that the solid phase becomes the dispersed phase and the water becomes the dispersing medium. Joffe (1949) reported that this reversal of phases greatly increases the reactivity of the constituents because of an increase in active surface. Under these conditions, it seems possible that a very intense weathering process occurs at the tops of the illuvial horizon.

It may be postulated that the chemical conditions prevailing upon solodization at the upper portion of the illuvial horizon are conducive to formation of clay-like minerals similar to vermiculite and montmorillonite either by alteration of micas or by condensation of hydroxylized aluminum compounds with polymerized silica. It seems

possible that chlorite formation takes place under the conditions of severe weathering prevailing at the upper illuvial horizons.

Solodization results in a relative deepening of the eluvial horizon unmatched by an increase in volume of the illuvial horizon. This phenomenon indicates either the possibility of a net loss of clay upon solodization or the eventuality of clay diffusion below the illuvial horizon in sufficiently low amounts to prevent its detection.

Barshad (1964) outlined a method that allows the calculation of the amount of clay formed and lost either by translocation or weathering for each horizon of a given profile. This method affords a quantitative measurement of some of the chemical and physical transformations resulting from pedogenesis.

In conclusion, Solonetzic soils throughout the world have received considerable attention. In recent years, considerable research work has been devoted to elucidate the effect of solodization upon clay mineralogy. Although significant progresses have been made in elucidating the process of solodization, the effect of this process upon the net amount of clay present in any given profile having undergone severe solodization is undetermined.

MATERIALS AND METHODS

Materials

Description of the Area

The sampling area lies in the Dark Brown zone which forms a transition between the bald prairie and the tree parkland of Alberta. The topography of this area is principally undulating to gently rolling. There is very little really level land. Sullivan Lake, one of the principal bodies of water of this area, lies at 2,681 feet of altitude and has no outlet at the present time (Wyatt, Newton, Bowser and Odynsky, 1938). Dowling Lake, the principal drainage basin of the sampling area has no well defined outlet, and consequently contains a great deal of alkali salts (Wyatt and Newton, 1927). The sampling area is characterized by the presence of numerous small meadows as well as the occurrence of clumps of poplar and willow depressions.

According to Coupland (Moss, 1955), the vegetation of the sampling area is classified as Mixed Prairie and is characterized by the Stipa - Bouteloua association. This association is dominated by six grass species, namely, Stipa comata, Stipa spartea var. curtiseta, Bouteloua gracilis, Agropyron dasystachyum, Agropyron smithii, and Koeleria cristata. The important shrubs of this association are Rosa arkansana and Artemisia cana.

The climate of the area is characterized by long, bright, moderately warm summer days and bright, cold, dry winter weather. According to McKay (1963), the area has a mean daily temperature for the year of approximately 37°F. and a mean annual precipitation of 13 to 14 inches. The frost-free period generally varies between 90 and 100

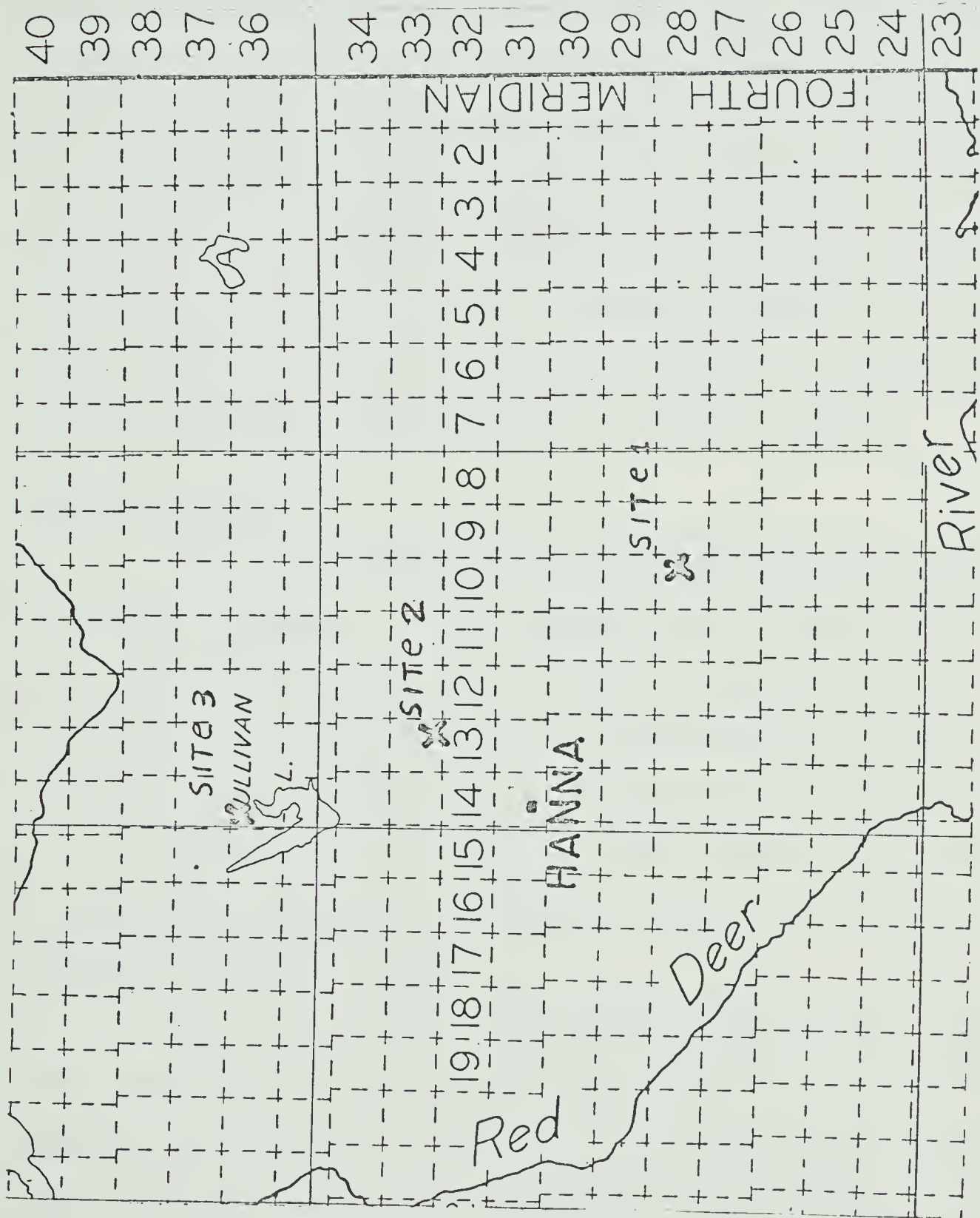


Figure 1. Map showing the sampling sites in the Dark Brown zone of Alberta.

days. The total hours of sunshine lies somewhere between 2,200 and 2,350 hours per year (Wyatt, Newton, Bowser and Odynsky, 1938).

According to Allan (1938), there is no evidence of thick morainal deposits occurring in the sampling area. The same author reports the presence of moraine-free areas in ranges 13 and 14 of the Sullivan Lake Sheet. However, the profiles chosen for this study were all developed on weakly to moderately calcareous saline till derived from the Edmonton formation. The Edmonton formation which underlies all of the sampling area belongs to the Upper Cretaceous. This formation consists of thin alternating beds of white and grey sandstones, silty sands, shales, black shales and coal (Kunkle, 1962).

Site Description

The three sampling areas in the Dark Brown zone of Alberta are shown in Figure 1. For each sampling area, at least two profiles showing visible differences in the degree of solodization were sampled. The profiles at each of the sites were sampled over relatively short distances (max. 100 feet) along gentle slopes of 2 to 6 per cent.

Cross-sections of the soil surface depicting the relative topographical positions of the profiles sampled at each of the three sites are presented in Figure 2.

At site 1, a Brown Solod and a Brown Solonetz were sampled. The sampling site was moderately well drained and no evidence of permanent water table was encountered at lower depths in the profiles. The two profiles were sampled approximately 30 feet apart on a relatively stone-free till derived from the Edmonton formation. The Brown Solod was sampled at the lowest topographical position of this site.



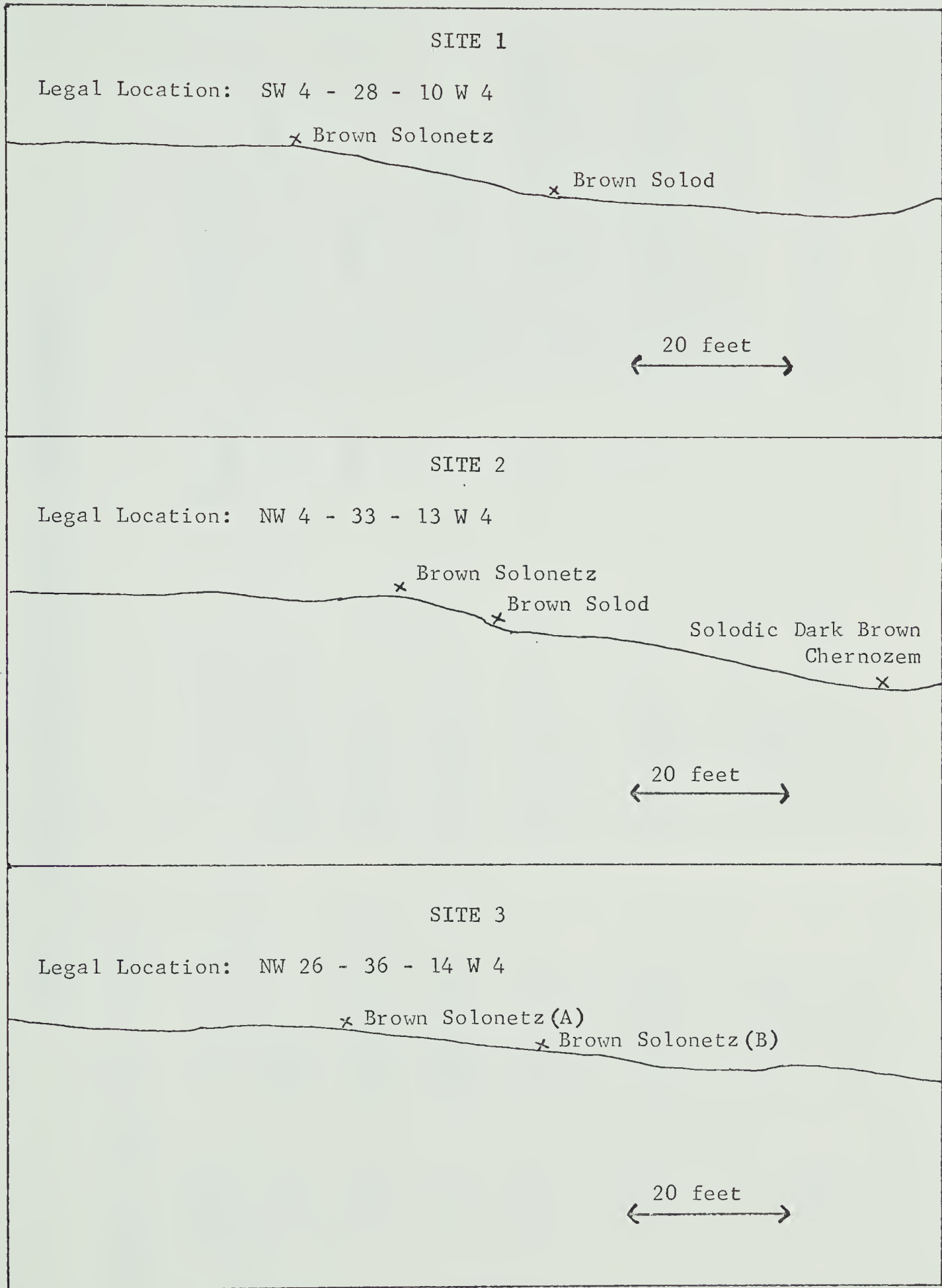


Figure 2. Cross-sections depicting the relative topographical positions of the profiles sampled.

TABLE I. PROFILE DESCRIPTION OF SITE 1 (BROWN SOLONETZ)

Legal Location: SW 4 - 28 - 10 W 4

| Horizon | Depth (cm.) | Color* Dry | Color* Moist | Texture | Structure and Consistency |
|----------------|----------------|----------------------------------|--------------------------------------|---------|---|
| Ah | 0-13 | Brown 10 YR 5/3 | Very dark greyish brown 10 YR 3/2 | SiL | Fine granular, friable |
| Ahe | 13-26 | Yellowish brown 10 YR 5/4 | Dark brown to brown 10 YR 4/3 | SiL | Platy, friable |
| Ae | 26-37 | Light brownish grey 10 YR 6/2 | Very dark greyish brown 10 YR 3/2 | SiL | Platy with remnants of tops of old columns, friable |
| Bnt | 37-50 | Pale brown 10 YR 6/3 | Dark greyish brown 10 YR 4/2 | CL | Flat topped columns break- ing to medium subangular blocky, very firm |
| BC | 50-61 | Pale brown 10 YR 6/3 | Dark greyish brown 10 YR 4/2 | SiL | Columnar breaking to medium subangular blocky, very firm |
| C ₁ | 61-78 | Pale brown 10 YR 6/3 | Dark greyish brown 10 YR 4/2 | L | Pseudo-blocky, firm |
| Cca | 78-96 | Pale brown 10 YR 6/3 | Dark greyish brown 10 YR 4/2 | L | Pseudo-blocky to massive, firm |

* Munsell colors

TABLE II. PROFILE DESCRIPTION OF SITE 1 (BROWN SOLOD)

Legal Location: SW 4 - 28 - 10 W 4

| Horizon | Depth (cm.) | Color* Dry | Color* Moist | Texture | Structure and Consistency |
|---------|----------------|----------------------------------|---------------------------------|---------|---|
| Ah | 0- 8 | Brown 10 YR 5/3 | Dark brown 10 YR 3/3 | SiL | Fine granular, friable |
| Ahe | 8-17 | Pale brown 10 YR 6/3 | Dark brown 10 YR 3/3 | SiL | Platy, friable |
| Ae | 17-27 | Light grey 10 YR 7/2 | Dark greyish brown 10 YR 4/2 | SiL | Platy, firm |
| AB | 27-33 | Light brownish grey 10 YR 6/2 | Dark greyish brown 10 YR 4/2 | SiL | Columnar breaking to irregular blocky to weak platy, firm |
| Bnt | 33-47 | Pale brown 10 YR 6/3 | Dark greyish brown 10 YR 4/2 | CL | Columnar breaking to sub- angular blocky, firm |
| C1 | 47-61 | Pale brown 10 YR 6/3 | Dark greyish brown 10 YR 4/2 | L | Coarse blocky to massive, firm |
| C2 | 61-73 | Pale brown 10 YR 6/3 | Dark greyish brown 10 YR 4/2 | L | Massive, firm |

* Munsell colors

TABLE III. PROFILE DESCRIPTION OF SITE 2 (SOLODIC DARK BROWN CHERNOZEM)

Legal Location: NW 4 - 33 - 13 W 4

| Horizon | Depth (cm.) | Color* Dry | Color* Moist | Texture | Structure and Consistency |
|---------|----------------|----------------------------|---------------------------------|---------|--|
| Ahe | 0- 9 | Brown 10 YR 5/3 | Dark brown 10 YR 3/3 | L | Fine granular to weak platy, friable |
| AB | 9-19 | Greyish brown 10 YR 5/2 | Dark greyish brown 10 YR 4/2 | L | Platy, friable |
| Bnjt | 19-39 | Pale brown 10 YR 6/3 | Dark greyish brown 10 YR 4/2 | L | Weak medium prismatic, firm |
| Bt | 39-59 | Pale brown 10 YR 6/3 | Dark greyish brown 10 YR 4/2 | SiL | Weak columnar breaking to medium blocky, firm |
| Cca | 59-88 | Pale brown 10 YR 6/3 | Dark greyish brown 10 YR 4/2 | L | Massive, firm |

* Munsell colors

TABLE IV. PROFILE DESCRIPTION OF SITE 2 (ERODED BROWN SOLOD)

Legal Location: NW 4 - 33 - 13 W 4

| Horizon | Depth (cm.) | Color* Dry | Color* Moist | Texture | Structure and Consistency |
|---------|----------------|-------------------------|----------------------------------|---------|---|
| Ahe | 0-10 | Brown 10 YR 5/3 | Dark brown 10 YR 3/3 | L | Platy, friable |
| AB | 10-26 | Pale brown 10 YR 6/3 | Dark brown to brown 10 YR 4/3 | L | Weak prismatic breaking to nuciform to coarse platy, firm |
| Bnt | 26-56 | Pale brown 10 YR 6/3 | Dark brown to brown 10 YR 4/3 | CL | Columnar breaking to blocky, very firm |
| C | 56-67 | Pale brown 10 YR 6/3 | Dark greyish brown 10 YR 4/2 | L | Massive, firm |

* Munsell colors

TABLE V. PROFILE DESCRIPTION OF SITE 2 (ERODED BROWN SOLONETZ)

Legal Location: NW 4 - 33 - 13 W 4

| Horizon | Depth (cm.) | Color* Dry | Color* Moist | Texture | Structure and Consistency |
|---------|----------------|----------------------------------|---------------------------------|---------|---|
| Ae | 0- 6 | Brown 10 YR 5/3 | Dark brown 10 YR 3/3 | L | Platy, friable |
| Bnt | 6-29 | Light brownish grey 10 YR 6/2 | Dark greyish brown 10 YR 4/2 | HvL | Columnar breaking to medium blocky, firm |
| Ccak | 29-57 | Light grey 10 YR 7/2 | Greyish brown 10 YR 5/2 | L | Medium blocky, firm |
| Csaca | 57-68 | Light grey 10 YR 7/2 | Greyish brown 10 YR 5/2 | L | Blocky to massive, firm |

* Munsell colors

TABLE VI. PROFILE DESCRIPTION OF SITE 3 (BROWN SOLONETZ(A))

Legal Location: NW 26 - 36 - 14 W 4

| Horizon | Depth (cm.) | Color* Dry | Color* Moist | Texture | Structure and Consistency |
|---------|----------------|----------------------------------|--------------------------------------|---------|---|
| Ah | 0- 10 | Dark greyish brown 10 YR 4/2 | Very dark greyish brown 10 YR 3/2 | L | Fine granular, friable |
| Ae | 10- 21 | Pale brown 10 YR 6/3 | Dark brown 10 YR 3/3 | L | Platy, friable |
| Bnt | 21- 44 | Light brownish grey 10 YR 6/2 | Dark greyish brown 10 YR 4/2 | CL | Strong columnar breaking to strong subangular blocky, very firm |
| BCsaca | 44- 62 | Light brownish grey 10 YR 6/2 | Dark grey 10 YR 4/1 | HvL | Medium angular blocky, firm |
| Csaca | 62- 96 | Grey to light grey 10 YR 6/1 | Dark greyish brown 10 YR 4/2 | HvL | Medium blocky, firm |
| Ck | 96-111 | Light brownish grey 10 YR 6/2 | Dark greyish brown 10 YR 4/2 | HvL | Blocky to massive, firm |

* Munsell colors

TABLE VII. PROFILE DESCRIPTION OF SITE 3 (BROWN SOLONETZ(B))

Legal Location: NW 26 - 36 - 14 W 4

| Horizon | Depth (cm.) | Color* Dry | Color* Moist | Texture | Structure and Consistency |
|------------------|----------------|----------------------------------|---------------------------------|---------|--|
| Ah | 0-9 | Dark greyish brown 10 YR 4/2 | Very dark brown 10 YR 2/2 | SL | Medium granular, friable |
| Ae | 9-19 | Brown 10 YR 5/2 | Dark brown 10 YR 3/3 | SL | Platy, friable |
| Bnt ₁ | 19-29 | Brown 10 YR 5/3 | Dark greyish brown 10 YR 4/2 | CL | Strong columnar breaking to medium subangular blocky, firm |
| Bnt ₂ | 29-41 | Light brownish grey 10 YR 6/2 | Dark greyish brown 10 YR 4/2 | CL | Columnar breaking to med- ium subangular blocky, very firm |
| BCsa | 41-54 | Light brownish grey 10 YR 6/2 | Dark greyish brown 10 YR 4/2 | HvL | Irregular angular blocky, firm |
| Csk | 54-69 | Light grey 10 YR 7/2 | Dark greyish brown 10 YR 4/2 | HvL | Blocky to massive, firm |
| Csca | 69-78 | Light brownish grey 10 YR 6/2 | Dark greyish brown 10 YR 4/2 | HvL | Massive, firm |

* Munsell colors

At site 2, a Solodic Dark Brown Chernozem, a Brown Solod, and a Brown Solonetz were sampled. The Brown Solod and Brown Solonetz were found in close association. The Brown Solod was located at the base of a small knoll while the Brown Solonetz was 10 feet up slope. The Solodic Dark Brown Chernozem was sampled in the lowest topographic position at a distance of approximately 30 feet away from the Brown Solod along a gentle slope of approximately 3 per cent. The Brown Solod and Solonetz profiles had 3 to 4 inches of drift material accumulated at the surface. The drift material was not sampled. All three profiles were sampled on relatively stone free till derived from the Edmonton formation and showing no visible stratification.

At site 3, two Brown Solonetz profiles depicting different degrees of solodization were sampled. The profiles were located 20 feet apart along a gentle slope of 2 to 3 per cent. The more solodized member was located at the lowest topographical position. The till, derived from the Edmonton formation, showed no visible signs of heterogeneity. The drainage of both profiles were well drained.

Methods

All profiles were sampled on a horizon basis. The samples were allowed to air dry at room temperature. The samples were then disaggregated to pass a 2 mm. sieve with a porcelain ball mill in order to avoid any iron contamination. The samples were then stored in non-sealing screw top containers.

1. Physical Analyses

(a) Mechanical analyses - Mechanical analyses of all samples were determined by the pipette method described by Toogood and Peters (1953). Salts were removed by repeated washing with distilled water. Samples containing calcium carbonate were treated with 0.1 N HCl. The organic matter was destroyed by the addition of 35 per cent H_2O_2 . Fine clay content was determined by evaporating and weighing an aliquot separated from the total clay fraction as suggested by Bayer (1959). The sand repartition percentage was also determined.

(b) Bulk density - The exact volume of each sample was calculated from the diameter of the core and the depth of the horizon. The bulk density was calculated on the basis of the air dry weight of each sample. In view of the cleanliness of the till, close replication was obtained by this technique.

2. Chemical Analyses

(a) Soil reaction - pH values were determined on a saturated soil paste, according to a method outlined by Doughty (1941). The apparatus used was a Beckman model zeromatic pH meter equipped with a glass electrode and a calomel electrode.

(b) Total nitrogen - Total nitrogen was determined by the Kjeldahl-Wilfarth-Gunning method (A.O.A.C., 1955). The catalyst used was HgO (0.41 g.), $CuSO_4$ (0.08 g.), and K_2SO_4 (9.9 g.) packaged in a polyethylene bag and sold commercially as Kel-pak. The ammonia was collected in a 4 per cent solution of H_3BO_3 according to the method suggested by Meeker and Wagner (1933) and titrated against standardized H_2SO_4 .

(c) Total carbon - Total carbon was determined with a Leco model 577-100 carbon analyser. The samples were ground to pass a 60-mesh sieve before being placed in the furnace.

(d) Free iron and aluminum - The aluminum and iron oxides were extracted by the dithionite-citrate-bicarbonate method outlined by Mehra and Jackson (1956). Iron and aluminum in the extracts were determined colorimetrically.

(e) Exchangeable cations and exchange capacity - Exchangeable cations were extracted from the samples with normal ammonium acetate adjusted to pH 7.0 as outlined in the A.O.A.C. (1955). The exchangeable cations were determined with the Perkin Elmer model 303 Atomic Absorption Spectrophotometer. The cation exchange capacity was determined by extracting the adsorbed ammonia with 1 N NaCl and distilling it according to the method outlined in the A.O.A.C. (1955).

(f) Exchange acidity - The exchange acidity was determined by leaching the soil with a 0.5 N barium acetate solution adjusted to pH 7.0. The leachate was then titrated with standard NaOH as suggested by Brown (1943).

(g) Electrical conductivity of saturation extracts - A saturation paste was prepared in accordance with the procedure outlined by the U.S. Salinity Laboratory Staff (1954). The saturation extracts were obtained with Metricell GA-8 filters under a pressure of 75 psi. The conductivity of the extract was measured with a direct reading Solu-Bridge Model RD-26.

(h) Soluble salts - The concentration of soluble cations (Na^+ , Ca^{++} , and Mg^{++}) in the saturation extracts were measured with the

Perkin Elmer Model 303 Atomic Absorption Spectrophotometer.

The bicarbonate content in the saturation extracts was determined with the use of a Radiometer titrator type T11b mounted with a glass electrode and a mercuric chloride calomel half-cell. The solution was titrated with 0.001 N H_2SO_4 to pH of 4.4. The determination of CO_3^{--} was not considered since the pH of the combined lower horizons for each profile did not exceed 8.0.

The sulfate content of the combined lower horizons was determined by the turbidmetric method (A.O.A.C., 1955). A Coleman spectrophotometer was used for the determination at a wavelength of 425 *mμ*.

The chloride content of the combined lower horizons was determined with the use of a Radiometer titrator type T11b equipped with a silver electrode and a mercuric sulfate calomel electrode. The solution was titrated with 0.001 N AgNO_3 solution until the potential of the solution was equal to a blank. Coagulation of the finer particles of the precipitate was facilitated by the addition of 25 ml. of 50 per cent acetic acid prior to titration. Arshad (1964) has found that this method ensures satisfactory recovery of Cl^- in the presence of Na_2CO_3 , NaHCO_3 , MgSO_4 , K_2SO_4 , and CaSO_4 .

3. Mineralogical Analyses

(a) Preparation of clay samples - Clay separation was carried out by the method outlined by Jackson (1949) with some modifications suggested by Pawluk (1961). The organic matter was removed with 35 per cent H_2O_2 . Soluble salts were washed out with distilled water. Samples containing carbonates were treated with 5 N HCl to pH of 5.0.

All samples were dispersed by adjusting the suspension to pH 8.0 with NaOH. The suspension was allowed to equilibrate overnight and the pH readjusted to 8.0. The separation of clay from the rest of the sample was accomplished by repeated decantation of the upper 8 cm. of suspension after standing 6 hours and 8 minutes. The settling time was calculated by Stoke's law (Baver, 1959).

A fine clay fraction ($< .2\mu$) was separated from the total clay fraction by centrifugation according to the method suggested by Baver (1959). The total and fine clay fractions were then saturated with calcium chloride and washed with distilled water to remove the excess of salts. The samples were then washed with ethanol. The first washings were made with 50 per cent ethanol while the final washings were made with 95 per cent ethanol. The clay fractions were then freeze-dried and stored in vials.

(b) X-ray analysis of clay minerals - The clay suspensions were mounted on glass slides according to the method of Kittrick (1961). Slides of both fine and total clay fractions were glycolated in a saturated atmosphere of ethylene glycol. Duplicate slides were heat-treated to 550°C. and stored in a dessicator. A Norelco X-ray diffractometer with a high angle goniometer was used for x-ray analysis of the clays. The X-ray unit was operated with a current of 15 ma. with a voltage of 35 kilowatts and had a copper K α radiation with a nickel filter.

(c) Surface area of clays - Surface area was determined using the method outlined by Heilman et al. (1965). The dry clay samples were saturated with ethylene glycol monoethyl ether and placed in the vacuum

dessicator along with a beaker of CaCl_2 and ethylene glycol monoethyl ether. A vacuum of 27 p.s.i.g. was applied until the weight of the sample became constant for two consecutive weighings. Repeated weighings were conducted after evacuation for a period of 3 hours at half-hour intervals. Arizona montmorillonite was used as the standard and is considered to have a surface area equal to 980 sq. m. per g.

(d) Differential thermal analyses - The samples were analysed with an Aminco Thermal Analyser model 4-4442. The clay samples were passed through a 300-mesh sieve and packed into the furnace. The fine clay samples were diluted 50 per cent by weight with ground, dry, γ alumina. Temperature rise was set at 16°C . per minute, thermocouple sensitivity was set at 0.5°C . per inch differential, and recorder sensitivity was set at 5 millivolts per division for the X axis and 1 millivolt per division for the Y axis. A nitrogen atmosphere was maintained for all samples at a flow rate of 40 cc. per minute.

(e) K_2O content of total clay fraction - For the determination of the K_2O content, 0.5 g. of clay was treated with a mixture of HF-HCl according to a method outlined by Pawluk (1967).

(f) C.E.C. of total clay fraction - Total clay samples weighing 0.5 g. were treated with 3 successive portions (40 ml.) of 1 N sodium acetate. The shaking intervals were 4, 4, and 12 hours, respectively. The samples were then washed free of excess sodium acetate with 3 successive washings of ethanol. The samples were then extracted with 3 treatments of 1 N ammonium acetate. The extracted sodium was determined

with the aid of a Perkin Elmer model 303 Atomic Absorption Spectrophotometer.

(g) Light mineral analyses - Approximately 200 to 300 g. of soil were wet-sieved and fine sand and very fine sand fractions were retained for analysis. The retained sand fractions were washed free of clay by treatment with dilute HCl and by boiling in distilled water. The light mineral fraction (S.G. \leq 2.80) was obtained by heavy liquid separation. The heavy liquid was adjusted to a density of 2.80 by mixing 9.09 parts of nitrobenzene with 90.91 parts of tetrabromoethane.

(h) Determination of quartz as index mineral - The percentage of quartz in the fine sand fraction was calculated by difference. The amount of K, Na, and Ca feldspars were first determined and their content was subtracted from 100 per cent. In order to do this, the fine sand fractions were brought into solution with an HF-HCl mixture according to the method outlined by Pawluk (1967). The concentration of Na, Ca, and K in the solution was determined on a Perkin Elmer model 303 Atomic Absorption Spectrophotometer. Identical analyses were also carried out on the very fine sand fractions. Feldspars were determined by allocating a content of 5.9 per cent of K₂O to potash feldspars, 8.5 per cent of Na₂O, and 4.95 per cent of CaO to soda-calcic feldspars.

RESULTS AND DISCUSSION

1. Physical Analyses

(a) Mechanical analyses - Tables VIII(a) to X indicate that the texture of the soils studied ranges from loam to clay loam. For all profiles studied, the percentage of total clay was highest in the illuvial horizon and decreased in the lower horizons. Theoretically, soils developed on uniform parent material have total clay content that increases with depth to a maximum which corresponds to the illuvial horizon. Below this depth, the total clay content decreases until it either remains constant or disappears, as in soils developed from consolidated rock (Barshad, 1964).

The Brown Solonetz soil at site 1 and the Eroded Brown Solonetz soil at site 2 (Tables VIII(a) and IX) show a slight but gradual increase of clay below the illuvial horizon. This departure from the expected pattern may be explained in terms of variability in the soil material itself or may be attributed to the inaccuracy inherent to the mechanical analyses method used.

Tables VIII(a) to X also show the fine clay distribution in each profile as a function of depth. The data indicate that the illuvial horizons of all profiles studied have the highest percentage of fine clay. This can be explained by the preferential translocation of finer clay material and its accumulation in the illuvial horizon and/or by the comminution of coarse clay particles into finer clay particles (Arshad and Pawluk I, 1966).

The C horizons have generally the highest sand percentage. The lower sand content of the upper horizons is attributed to either non-

TABLE VIII(a). SOME PHYSICAL ANALYSES OF SOILS FROM SITE 1

Classification: Brown Solonetz

| Horizon | Depth (cm.) | Mechanical Analysis | | | | | |
|----------------|----------------|---------------------|-----------|---------------------|-----------------|-------------------------------|-----------------------------|
| | | Sand % | Silt % | Total Nonclay* % | Total Clay % | Coarse Clay ¹ % | Fine Clay ² % |
| Ah | 0-13 | 30 | 52 | 82 | 18 | 10 | 8 |
| Ahe | 13-26 | 30 | 57 | 87 | 13 | 12 | 1 |
| Ae | 26-37 | 31 | 61 | 92 | 8 | 7 | 1 |
| Bnt | 37-50 | 33 | 40 | 73 | 27 | 20 | 7 |
| BC | 50-61 | 35 | 47 | 82 | 18 | 16 | 2 |
| C ₁ | 61-78 | 42 | 39 | 81 | 19 | 17 | 2 |
| Cca | 78-96 | 44 | 35 | 79 | 21 | 19 | 2 |

¹ 2.0-0.2 microns

* Sand % + Silt %

² less than 0.2 microns

TABLE VIII(b). SOME PHYSICAL ANALYSES OF SOILS FROM SITE 1

Classification: Brown Solod

| Horizon | Depth (cm.) | Mechanical Analysis | | | | | |
|----------------|----------------|---------------------|-----------|---------------------|-----------------|-------------------------------|-----------------------------|
| | | Sand % | Silt % | Total Nonclay* % | Total Clay % | Coarse Clay ¹ % | Fine Clay ² % |
| Ah | 0- 8 | 29 | 49 | 78 | 22 | 14 | 8 |
| Ahe | 8-17 | 22 | 60 | 82 | 18 | 9 | 9 |
| Ae | 17-27 | 21 | 63 | 84 | 16 | 9 | 7 |
| AB | 27-33 | 24 | 50 | 74 | 26 | 8 | 18 |
| Bnt | 33-47 | 33 | 36 | 69 | 31 | 6 | 25 |
| C ₁ | 47-61 | 40 | 36 | 76 | 24 | 12 | 12 |
| C ₂ | 61-73 | 42 | 35 | 77 | 23 | 11 | 12 |

1 2.0-0.2 microns

* Sand % + Silt %

2 less than 0.2 microns

TABLE IX. SOME PHYSICAL ANALYSES OF SOILS FROM SITE 2

| Mechanical Analysis | | | | | | | |
|--|----------------|-----------|-----------|---------------------|-----------------|-------------------------------|-----------------------------|
| Horizon | Depth (cm.) | Sand % | Silt % | Total Nonclay* % | Total Clay % | Coarse Clay ¹ % | Fine Clay ² % |
| Classification: Solodic Dark Brown Chernozem | | | | | | | |
| Ahe | 0- 9 | 42 | 45 | 87 | 13 | 3 | 10 |
| AB | 9-19 | 36 | 42 | 78 | 22 | 6 | 16 |
| Bnjt | 19-39 | 37 | 41 | 78 | 22 | 9 | 13 |
| Bt ₂ | 39-59 | 25 | 48 | 73 | 27 | 8 | 19 |
| Cca | 59-88 | 50 | 32 | 82 | 18 | 13 | 5 |
| Classification: Eroded Brown Solod | | | | | | | |
| Ahe | 0-10 | 40 | 44 | 84 | 16 | 5 | 11 |
| AB | 10-26 | 37 | 40 | 77 | 23 | 2 | 21 |
| Bnt | 26-56 | 26 | 46 | 72 | 28 | 7 | 21 |
| C | 56-67 | 42 | 38 | 80 | 20 | 4 | 16 |
| Classification: Eroded Brown Solonetz | | | | | | | |
| Ae | 0- 6 | 38 | 49 | 87 | 13 | 5 | 8 |
| Bnt | 6-29 | 33 | 39 | 72 | 28 | 4 | 24 |
| Ccak | 29-57 | 41 | 43 | 84 | 16 | 13 | 3 |
| Csaca | 57-68 | 43 | 40 | 83 | 17 | 12 | 5 |

¹ 2.0-0.2 microns

² less than 0.2 microns

* Sand % + Silt %

TABLE X. SOME PHYSICAL ANALYSES OF SOILS FROM SITE 3

| Horizon | Depth (cm.) | Sand % | Silt % | Total Nonclay* % | Mechanical Analysis | | |
|------------------------------------|----------------|-----------|-----------|---------------------|---------------------|-------------------------------|-----------------------------|
| | | | | | Total Clay % | Coarse Clay ¹ % | Fine Clay ² % |
| Classification: Brown Solonetz (A) | | | | | | | |
| Ah | 0- 10 | 39 | 44 | 83 | 17 | 8 | 9 |
| Ae | 10- 21 | 46 | 34 | 80 | 20 | 8 | 12 |
| Bnt | 21- 44 | 46 | 24 | 70 | 30 | 10 | 20 |
| BCsaca | 44- 62 | 41 | 32 | 73 | 27 | 15 | 12 |
| Csaca | 62- 96 | 43 | 29 | 72 | 28 | 16 | 12 |
| Ck | 96-111 | 41 | 30 | 71 | 29 | 14 | 15 |
| Classification: Brown Solonetz (B) | | | | | | | |
| Ah | 0- 9 | 44 | 46 | 90 | 10 | 2 | 8 |
| Ae | 9-19 | 55 | 30 | 85 | 15 | 3 | 12 |
| Bnt ₁ | 19-29 | 41 | 30 | 71 | 29 | 7 | 22 |
| Bnt ₂ | 29-41 | 40 | 31 | 71 | 29 | 8 | 21 |
| BCsa | 41-54 | 41 | 33 | 74 | 26 | 10 | 16 |
| Csk | 54-69 | 43 | 30 | 73 | 27 | 10 | 17 |
| Csca | 69-78 | 46 | 34 | 80 | 20 | 13 | 7 |

1 2.0-0.2 microns. 2 less than 0.2 microns. * Sand % + Silt %.

uniformity of the parent material or to disintegration of coarser sand material into particles of finer diameter. David (1966) reported similar upward reduction of the particle mean size in some Saskatchewan paleosols and attributes it to disintegration of coarse material. Gravenor (1954) reported that disappearance of pebbles and upward reduction in grain size are characteristics of weathered tills. Further evidence of disintegration is provided by the general decrease in the content of silt size material compensated for by an increase in the content of sand size material with progressive increase in profile depth. As shown in Tables VIII(a) to X, the nonclay percentage is generally uniform in the BC and C horizons, decreases markedly in the illuvial horizons, and is highest in the eluvial horizons. Consequently, the pedogenic type of clay distribution encountered in all profiles indicates homogeneity in the original material from which the soil profiles developed.

Sand particle-size distribution and bulk density data are reported in Tables XI to XIII. The content of the various sand separates is expressed in percentage of the total weight of the sand fraction. The data reported in these tables indicates that the fine and very fine sand fractions constitute between 65 and 89 per cent of the total sand fraction. The amount of very fine sand occurring in the profiles at sites 1 and 3 decreases with depth (Tables XI(a) and XIII). Profiles at site 2 show no definite pattern for sand particle size distribution. The very marked decrease in the very fine sand content occurring in the profiles of site 1 may be related to the progressive increase of the content of very coarse, coarse, and medium sand with profile depth. Gravenor (1954) reported that sand particle size

TABLE XI(a). SAND PARTICLE SIZE DISTRIBUTION AND BULK DENSITY VALUES. SITE 1

Classification: Brown Solonetz

| Horizon | Depth (cm.) | Sand Fractions* | | | | | Bulk Density g./cc. |
|----------------|----------------|-----------------|------|------|------|--------|------------------------|
| | | V.C.S. | C.S. | M.S. | F.S. | V.F.S. | |
| Ah | 0-13 | 1 | 6 | 9 | 41 | 43 | .80 |
| Ahe | 13-26 | 2 | 6 | 9 | 39 | 44 | .88 |
| Ae | 26-37 | 3 | 5 | 5 | 36 | 51 | 1.02 |
| Bnt | 37-50 | 1 | 10 | 10 | 43 | 36 | 1.19 |
| BC | 50-61 | 4 | 9 | 11 | 40 | 36 | 1.50 |
| C ₁ | 61-78 | 2 | 10 | 12 | 42 | 34 | 1.32 |
| Cca | 78-96 | 3 | 11 | 13 | 42 | 31 | 1.34 |

* Sand fraction expressed as percentage of total weight of sand

TABLE XI(b). SAND PARTICLE SIZE DISTRIBUTION AND BULK DENSITY VALUES. SITE 1

Classification: Brown Solod

| Horizon | Depth (cm.) | Sand Fractions* | | | | | Bulk Density g./cc. |
|----------------|----------------|-----------------|------|------|------|--------|------------------------|
| | | V.C.S. | C.S. | M.S. | F.S. | V.F.S. | |
| Ah | 0- 8 | 2 | 7 | 9 | 44 | 38 | .88 |
| Ahe | 8-17 | 2 | 7 | 11 | 38 | 42 | .88 |
| Ae | 17-27 | 2 | 7 | 11 | 35 | 45 | 1.07 |
| AB | 27-33 | 3 | 10 | 14 | 36 | 37 | 1.18 |
| Bnt | 33-47 | 4 | 13 | 18 | 37 | 28 | 1.27 |
| C ₁ | 47-61 | 4 | 13 | 18 | 39 | 26 | 1.37 |
| C ₂ | 61-73 | 4 | 12 | 17 | 39 | 28 | 1.38 |

* Sand fractions expressed as percentage of total weight of sand

TABLE XII. SAND PARTICLE SIZE DISTRIBUTION AND BULK DENSITY VALUES. SITE 2

| Horizon | Depth (cm.) | Sand Fractions* | | | | | Bulk Density g./cc. |
|--|----------------|-----------------|------|------|------|--------|------------------------|
| | | V.C.S. | C.S. | M.S. | F.S. | V.F.S. | |
| Classification: Solodic Dark Brown Chernozem | | | | | | | |
| Ahe | 0- 9 | 3 | 6 | 10 | 47 | 34 | .99 |
| AB | 9-19 | 3 | 7 | 12 | 48 | 30 | 1.10 |
| Bnjt | 19-39 | 2 | 7 | 10 | 49 | 32 | 1.23 |
| Bt | 39-59 | 2 | 6 | 10 | 48 | 34 | 1.34 |
| Cca | 59-88 | 2 | 6 | 9 | 50 | 33 | 1.28 |
| Classification: Eroded Brown Solod | | | | | | | |
| Ahe | 0-10 | 2 | 7 | 7 | 55 | 29 | 1.02 |
| AB | 10-26 | 2 | 7 | 11 | 48 | 32 | 1.11 |
| Bnt | 26-56 | 2 | 7 | 9 | 51 | 31 | 1.27 |
| C | 56-67 | 2 | 6 | 9 | 55 | 28 | 1.30 |
| Classification: Eroded Brown Solonetz | | | | | | | |
| Ae | 0- 6 | 1 | 5 | 6 | 63 | 25 | .97 |
| Bnt | 6-29 | 2 | 6 | 9 | 53 | 30 | 1.24 |
| Ccak | 29-57 | 3 | 7 | 11 | 50 | 29 | 1.21 |
| Csaca | 57-68 | 2 | 7 | 12 | 50 | 29 | 1.37 |

* Sand fractions expressed as percentage of total weight of sand

TABLE XIII. SAND PARTICLE SIZE DISTRIBUTION AND BULK DENSITY VALUES. SITE 3

| Horizon | Depth (cm.) | Classification: Brown Solonetz (A) | Sand Fractions* | | | | | Bulk Density g./cc. |
|---------|----------------|------------------------------------|-----------------|------|------|------|--------|------------------------|
| | | | V.C.S. | C.S. | M.S. | F.S. | V.F.S. | |
| Ah | 0- 10 | 1 | | 7 | 3 | 48 | 41 | 1.04 |
| Ae | 10- 21 | 3 | | 7 | 8 | 44 | 38 | 1.10 |
| Bnt | 21- 44 | 4 | | 12 | 14 | 35 | 35 | 1.18 |
| BCsaca | 44- 62 | 3 | | 9 | 14 | 48 | 26 | 1.22 |
| Csaca | 62- 96 | 3 | | 11 | 16 | 46 | 24 | 1.37 |
| Ck | 96-111 | 3 | | 10 | 13 | 48 | 26 | 1.38 |

| | | | | | | | | |
|------------------------------------|-------|---|--|----|----|----|----|------|
| Classification: Brown Solonetz (B) | | | | | | | | |
| Ah | 0- 9 | 2 | | 9 | 9 | 48 | 32 | .92 |
| Ae | 9-19 | 2 | | 8 | 12 | 46 | 32 | 1.02 |
| Bnt ₁ | 19-29 | 3 | | 9 | 12 | 47 | 30 | 1.14 |
| Bnt ₂ | 29-41 | 2 | | 9 | 14 | 48 | 27 | 1.31 |
| BCsa | 41-54 | 2 | | 10 | 13 | 50 | 25 | 1.35 |
| Csk | 54-69 | 2 | | 8 | 14 | 50 | 26 | 1.50 |
| Csca | 69-78 | 2 | | 8 | 13 | 49 | 28 | 1.33 |

* Sand fractions expressed as percentage of total weight of sand

distribution such as those occurring at site 1 and 2 may have resulted from disintegration of pebbles and boulders into smaller particles which mainly belong to the medium and fine sand sizes.

(b) Bulk density - Bulk density values are reported in Tables XI(a) to XIII. Buckman and Brady (1960) reported that soil bulk density may commonly attain 1.80 or 2.00 g./cc. The bulk densities of the soils studied range from 0.80 to 1.50 g./cc. The low values for bulk density found for the surface horizons may be attributed to their high organic matter content and greater degree of granulation. However, the highest bulk density values are encountered in the illuvial horizons and/or in the C horizons. Since illuviated clay occupies the void in the B horizons, it is expected that their structural units would have a high bulk density. The fact that some illuvial horizons have a lower bulk density than their corresponding C horizons likely reflects the influence of large voids and plant roots which occur at the interfaces of the structural units. The higher bulk density values sometimes encountered in the C horizons may thus be at least partially attributed to their more massive structure. Although higher bulk density values in lower horizons may also partly result from compaction and/or heterogeneity of the soil parent material, particle size distribution indicates uniformity in the parent material of all profiles under consideration.

2. Chemical Analyses

(a) Soil reaction - The pH values of the soils studied (Tables XIV(a) and XIV(b)) range from 4.9 to 6.5 in the A horizons, 5.3 to 8.0 in the B horizons, and from 6.4 to 8.7 in the C horizons. The lowest pH values are encountered in Ae horizons and/or in the upper B horizons (or

TABLE XIV

(See over)

TABLE XIV. SOME CHEMICAL ANALYSES

| Hor. | Depth (cm.) | pH | EC x mmhos./cm. | Soluble Cations | | | Soluble Anions | | | Sat. % |
|---|----------------|-----|--------------------|-----------------|------------------|------------------|-------------------------------|-----------------|-------------------------------|-----------|
| | | | | Na ⁺ | Ca ⁺⁺ | Mg ⁺⁺ | HCO ₃ ⁻ | Cl ⁻ | SO ₄ ⁻⁻ | |
| me. / 100 g. of soil | | | | | | | | | | |
| Classification: Brown Solonetz (Site 1) | | | | | | | | | | |
| Ah | 0-13 | 3.6 | - | - | - | - | - | - | - | - |
| Ahe | 13-26 | 5.7 | - | - | - | - | - | - | - | - |
| Ae | 26-37 | 6.7 | - | - | - | - | - | - | - | - |
| Bnt | 37-50 | 7.8 | - | - | - | - | - | - | - | - |
| BC | 50-61 | 8.0 | - | - | - | - | - | - | - | - |
| C ₁ | 61-78 | 8.3 | | | | | | | | |
| Cca | 78-96 | 8.1 | 2.6 | 1.1 | 0.1 | 0.2 | 0.3 | 0.4 | 0.4 | 37.6 |
| Classification: Brown Solod (Site 1) | | | | | | | | | | |
| Ah | 0- 8 | 6.3 | - | - | - | - | - | - | - | - |
| Ahe | 8-17 | 6.3 | - | - | - | - | - | - | - | - |
| Ae | 17-27 | 6.5 | - | - | - | - | - | - | - | - |
| AB | 27-33 | 7.1 | - | - | - | - | - | - | - | - |
| Bnt | 33-47 | 7.9 | - | - | - | - | - | - | - | - |
| C ₁ | 47-61 | 8.1 | | | | | | | | |
| C ₂ | 61-73 | 8.0 | 2.4 | 1.3 | 0.2 | 0.2 | 0.2 | 0.5 | 0.6 | 59.0 |
| Classification: Solodic Dark Brown Chernozem (Site 2) | | | | | | | | | | |
| Ahe | 0- 9 | 5.1 | - | - | - | - | - | - | - | - |
| AB | 9-19 | 5.2 | - | - | - | - | - | - | - | - |
| Bntj | 19-39 | 5.4 | - | - | - | - | - | - | - | - |
| Bt | 39-59 | 5.8 | 0.2 | 0.1 | T* | T | T | T | T | 60.0 |
| Cca | 59-88 | 7.1 | 0.6 | 0.1 | 0.1 | 0.1 | 0.2 | T | T | 53.0 |

* Less than 0.05

TABLE XIV. (CONTINUED)

| Exchangeable Cations* | | | | | C.E.C. me/100 g. Soil | CaCO ₃ Equiv. % | Organic Carbon % | N % | C/N | Dithionite | |
|---|-----------------------|----------------------|---------------------|-----------------------|-----------------------------|----------------------------------|------------------------|--------|------|-------------------------------------|-------------------------------------|
| Ca ⁺⁺ % | Mg ⁺⁺ % | Na ⁺ % | K ⁺ % | H ⁺⁺⁺ % | | | | | | Fe ₂ O ₃ % | Al ₂ O ₃ % |
| Classification: Brown Solonetz (Site 1) | | | | | | | | | | | |
| 45.5 | 19.9 | 1.7 | 3.8 | 29.1 | 14.9 | - | 3.7 | 0.30 | 12.2 | 0.42 | 0.13 |
| 38.8 | 23.0 | 1.5 | 3.9 | 32.8 | 11.1 | - | 1.6 | 0.14 | 11.1 | 0.39 | 0.09 |
| 39.1 | 26.3 | 7.5 | 5.9 | 21.2 | 9.5 | - | 0.9 | 0.08 | 11.0 | 0.40 | 0.11 |
| 34.2 | 45.2 | 15.6 | 4.4 | 0.6 | 21.8 | 0.3 | 0.6 | 0.07 | 8.3 | 0.43 | 0.11 |
| 36.7 | 43.6 | 14.8 | 4.6 | 0.3 | 21.9 | 0.5 | 0.6 | 0.07 | 8.0 | 0.46 | 0.13 |
| 54.2 | 31.6 | 11.7 | 2.5 | 0 | 16.7 | 0.9 | - | - | - | 0.32 | 0.11 |
| 56.8 | 30.9 | 9.5 | 2.7 | 0.1 | 15.9 | 1.5 | - | - | - | 0.33 | 0.09 |
| Classification: Brown Solod (Site 1) | | | | | | | | | | | |
| 51.4 | 26.6 | 1.0 | 2.1 | 16.2 | 14.7 | - | 1.8 | 0.17 | 10.8 | 0.30 | 0.09 |
| 48.0 | 31.6 | 2.9 | 3.6 | 13.9 | 14.1 | - | 1.2 | 0.12 | 9.7 | 0.36 | 0.09 |
| 52.1 | 24.8 | 8.5 | 5.5 | 9.1 | 9.0 | - | 0.8 | 0.08 | 10.0 | 0.40 | 0.09 |
| 29.7 | 44.2 | 15.1 | 7.0 | 4.0 | 15.7 | - | 0.7 | 0.08 | 9.1 | 0.34 | 0.11 |
| 43.1 | 40.2 | 11.1 | 4.9 | 0.7 | 20.3 | 0.4 | 0.7 | 0.08 | 8.4 | 0.63 | 0.13 |
| 49.6 | 35.2 | 11.1 | 3.7 | 0.4 | 18.2 | 0.5 | - | - | - | 0.63 | 0.13 |
| 41.5 | 38.9 | 14.2 | 3.5 | 1.9 | 15.7 | 0 | - | - | - | 0.64 | 0.13 |
| Classification: Solodic Dark Brown Chernozem (Site 2) | | | | | | | | | | | |
| 25.9 | 13.7 | 3.6 | 2.2 | 54.6 | 13.4 | - | 1.4 | 0.14 | 9.7 | 0.66 | 0.19 |
| 50.6 | 19.8 | 2.8 | 1.9 | 24.9 | 16.5 | - | 1.2 | 0.10 | 12.3 | 0.63 | 0.15 |
| 56.5 | 27.2 | 2.2 | 1.4 | 12.7 | 17.6 | - | 0.8 | 0.06 | 12.8 | 0.53 | 0.13 |
| 61.9 | 26.0 | 2.9 | 1.3 | 7.9 | 22.5 | 0.3 | 0.6 | 0.05 | 12.0 | 0.60 | 0.19 |
| 80.3 | 16.5 | 1.4 | 0.6 | 1.2 | 14.8 | 1.2 | 0.6 | - | - | 0.64 | 0.15 |

* Percentages based on the summation of the cations determined

** Exchange acidity

TABLE XIV(a)

(See over)

TABLE XIV(a). SOME CHEMICAL ANALYSES

| Hor. | Depth (cm.) | pH | EC x mmhos./cm. | Soluble Cations | | | Soluble Anions | | | Sat. % |
|--|----------------|-----|--------------------|-----------------|------------------|------------------|-------------------------------|-----------------|-------------------------------|-----------|
| | | | | Na ⁺ | Ca ⁺⁺ | Mg ⁺⁺ | HCO ₃ ⁻ | Cl ⁻ | SO ₄ ⁻⁻ | |
| me. / 100 g. of soil | | | | | | | | | | |
| Classification: Eroded Brown Solod (Site 2) | | | | | | | | | | |
| Ahe | 0- 10 | 5.2 | - | - | - | - | - | - | - | - |
| AB | 10- 26 | 4.9 | - | - | - | - | - | - | - | - |
| Bnt | 26- 56 | 5.3 | 0.6 | 0.3 | 0.1 | T* | 0.1 | T | 0.1 | 48.0 |
| C | 56- 67 | 6.4 | 0.7 | 0.3 | 0.1 | T | 0.2 | T | T | 53.0 |
| Classification: Eroded Brown Solonetz (Site 2) | | | | | | | | | | |
| Ae | 0- 6 | 5.9 | - | - | - | - | - | - | - | - |
| Bnt | 6- 29 | 7.6 | - | - | - | - | - | - | - | - |
| Ccak | 29- 57 | 8.7 | 9.5 | 1.3 | 1.3 | 2.1 | 0.2 | 0.1 | 4.8 | 80.0 |
| Csaca | 57- 68 | 8.2 | 9.5 | 1.2 | 1.3 | 1.8 | 0.1 | 0.1 | 4.9 | 81.0 |
| Classification: Brown Solonetz (A) (Site 3) | | | | | | | | | | |
| Ah | 0- 10 | 5.6 | - | - | - | - | - | - | - | - |
| Ae | 10- 21 | 5.5 | - | - | - | - | - | - | - | - |
| Bnt | 21- 44 | 6.8 | - | - | - | - | - | - | - | - |
| BCsaca | 44- 62 | 7.6 | 3.5 | 0.2 | 1.6 | 1.3 | 0.1 | T | 2.3 | 70.0 |
| Csaca | 62- 96 | 7.7 | 3.7 | 0.2 | 1.7 | 1.6 | 0.1 | T | 2.6 | 73.0 |
| Ck | 96-111 | 7.6 | 3.5 | 0.2 | 1.6 | 1.6 | 0.1 | T | 2.6 | 72.0 |
| Classification: Brown Solonetz (B) (Site 3) | | | | | | | | | | |
| Ah | 0- 9 | 5.4 | - | - | - | - | - | - | - | - |
| Ae | 9- 19 | 5.6 | - | - | - | - | - | - | - | - |
| Bnt ₁ | 19- 29 | 6.6 | - | - | - | - | - | - | - | - |
| Bnt ₂ | 29- 41 | 7.5 | - | - | - | - | - | - | - | - |
| BCsa | 41- 54 | 7.6 | 7.4 | 0.9 | 1.6 | 2.6 | 0.2 | T | 4.0 | 84.0 |
| Csk | 54- 69 | 7.6 | 7.2 | 0.7 | 1.6 | 2.2 | 0.2 | 0.1 | 3.2 | 77.0 |
| Csca | 69- 78 | 7.7 | 3.4 | 0.2 | 1.6 | 1.5 | 0.1 | 0.1 | 2.9 | 69.0 |

* Less than 0.05

TABLE XIV(a). (CONTINUED)

| Exchangeable Cations* | | | | | C.E.C. me/100 g. Soil | CaCO ₃ Equiv. % | Organic Carbon % | N % | C/N | Dithionite | |
|--|-----------------------|----------------------|---------------------|-----------------------|-----------------------------|----------------------------------|------------------------|--------|------|-------------------------------------|-------------------------------------|
| Ca ⁺⁺ % | Mg ⁺⁺ % | Na ⁺ % | K ⁺ % | H ⁺⁺⁺ % | | | | | | Fe ₂ O ₃ % | Al ₂ O ₃ % |
| Classification: Eroded Brown Solod (Site 2) | | | | | | | | | | | |
| 33.6 | 14.9 | 3.1 | 1.3 | 47.1 | 11.5 | - | 1.3 | 0.14 | 9.3 | 0.63 | 0.17 |
| 51.8 | 20.8 | 4.0 | 1.3 | 22.1 | 17.0 | - | 0.8 | 0.08 | 10.0 | 0.40 | 0.21 |
| 53.7 | 26.9 | 6.0 | 1.0 | 12.4 | 20.7 | - | 0.8 | 0.06 | 13.3 | 0.77 | 0.09 |
| 67.5 | 26.2 | 5.2 | 1.1 | 0 | 18.3 | 0 | - | - | - | 0.87 | 0.08 |
| Classification: Eroded Brown Solonetz (Site 2) | | | | | | | | | | | |
| 21.0 | 8.4 | 3.6 | 2.0 | 64.5 | 12.8 | - | 1.5 | 0.16 | 9.4 | 0.66 | 0.08 |
| 9.1 | 51.9 | 36.9 | 1.4 | 0.7 | 22.1 | - | 1.1 | 0.11 | 10.0 | 0.73 | 0.08 |
| 51.5 | 24.5 | 23.4 | 0.6 | 0 | 15.7 | 2.1 | - | - | - | 0.60 | 0.08 |
| 66.4 | 23.1 | 9.7 | 0.7 | 0.1 | 12.5 | 6.0 | - | - | - | 0.73 | 0.08 |
| Classification: Brown Solonetz (A) (Site 3) | | | | | | | | | | | |
| 35.3 | 16.5 | 1.2 | 4.5 | 42.5 | 12.9 | - | 2.2 | 0.23 | 9.6 | 0.60 | 0.08 |
| 36.4 | 32.6 | 1.3 | 2.9 | 26.8 | 10.6 | - | 1.1 | 0.12 | 9.2 | 0.72 | 0.06 |
| 39.3 | 54.3 | 2.1 | 1.5 | 2.8 | 13.1 | - | 0.6 | 0.06 | 10.0 | 0.56 | 0.06 |
| 66.6 | 30.2 | 1.7 | 0.9 | 0.6 | 18.9 | 2.6 | - | - | - | 0.52 | 0.06 |
| 66.2 | 30.2 | 2.4 | 0.8 | 0.4 | 16.5 | 2.8 | - | - | - | 0.59 | 0.08 |
| 86.0 | 13.0 | 0.6 | 0 | 0.4 | 16.3 | 1.8 | - | - | - | 0.60 | 0.08 |
| Classification: Brown Solonetz (B) (Site 3) | | | | | | | | | | | |
| 41.1 | 13.5 | 1.8 | 2.0 | 41.6 | 14.4 | - | 2.7 | 0.27 | 10.0 | 0.67 | 0.09 |
| 36.1 | 30.0 | 9.7 | 1.7 | 22.5 | 12.0 | - | 1.0 | 0.11 | 9.1 | 0.56 | 0.04 |
| 32.1 | 52.8 | 9.1 | 1.3 | 4.7 | 15.0 | - | 1.0 | 0.09 | 11.1 | 0.69 | 0.09 |
| 31.8 | 55.7 | 10.0 | 1.3 | 1.2 | 23.7 | 0.1 | 0.8 | 0.07 | 11.4 | 0.66 | 0.08 |
| 36.8 | 51.0 | 10.3 | 1.2 | 0.7 | 20.9 | 0.8 | - | - | - | 0.66 | 0.08 |
| 34.5 | 54.3 | 8.3 | 1.2 | 1.7 | 18.1 | 1.4 | - | - | - | 0.70 | 0.08 |
| 35.2 | 52.1 | 9.1 | 2.0 | 1.6 | 16.0 | 1.9 | - | - | - | 0.66 | 0.08 |

* Percentages based on the summation of the cations determined

** Exchange acidity

transitional AB horizons) suggesting that the maximum intensity of pedogenesis may be expected to occur at the point of contact between the eluvial and illuvial horizons. High pH of the B and C horizons are attributable to the high percentage of basic cation adsorbed onto the exchange complex. Likewise, low pH values generally correlate with high exchange acidity. The Solodic Dark Brown Chernozem and Eroded Brown Solod profiles at site 2 have lowest pH values in their upper sola. This suggests that these soils have been subjected to the greatest degree of solodization. The pH values reported are in accordance with results obtained for similar soils (Bentley and Rost, 1947; Arshad, 1964; and Bowser, 1965).

(b) Electrical conductivity and soluble salts - The electrical conductivity and soluble cations in soil-water extracts are reported in Tables XIV and XIV(a). The electrical conductivity varies greatly among the different profiles studied. As indicated in Tables XIV and XIV(a), all horizons having pH values less than 7.5 have very low quantities of soluble salts present. Within each sampling site, the soluble salt content extracted from the soil profile decreases progressively with an increase in the degree of solodization. This is in agreement with the fact that increased solodization is accompanied by downward removal of the salt layer (Bowser, 1965). The highest electrical conductivity values are obtained in water samples extracted from the C horizons of the Eroded Brown Solonetz at site 2 while lowest values are obtained for extracts from the lower horizons of the Solodic Dark Brown Chernozem at site 2. Sodium is the dominant water soluble cation present at site 1. Electrical conductivity and soluble salt values reported for site 1 are based on composite samples of the C₁ and C₂ horizons. The Solodic Dark

Brown Chernozem at site 2 has sodium as the dominant water-soluble cation as well although the quantity of soluble salts present is negligible. The highest amount of soluble salts is extracted from the lower horizons of the Eroded Brown Solonetz at site 2 where a dominance of soluble magnesium occurs. At site 3 where the extracts from the two Brown Solonetz profiles have intermediate soluble salt content, soluble sodium and magnesium ions account for more than 50 per cent of the total cation content.

Sulfates form the bulk of the soluble anions in the extracts from all profiles studied. Very low amounts of chlorides and bicarbonates and no carbonates are detected. Although the chloride and bicarbonate ions extracted from the profiles of site 1 are low, they nevertheless account for more than 50 per cent of all anions present. This is in sharp contrast with the other profiles studied in which the sulfate ion constitutes the overwhelming portion of the anions present in the soluble salt extracts. The results reported are in agreement with those found by Bowser (1965). This same author reports that sulfates of sodium, magnesium, and calcium are the most common salts present in the soils of Western Canada while carbonates, bicarbonates, and chlorides are only sometimes present.

The saturation percentages of the soils studied are reported in Tables XIV and XIV(a). The saturation percentage is influenced by the texture of the soil, the kind and amount of clay present as well as the amount of salts (U.S. Salinity Laboratory Staff, 1954). In this study, the saturation percentage values are utilized for the conversion of the values for soluble salt concentration in the saturation extracts to concentrations in terms of soil weight (me./100 g.).

(c) Exchangeable cations and exchange capacity - The percentage of exchangeable cations and the exchange capacity of all soils studied are reported in Tables XIV and XIV(a). High cation exchange capacities of the surface horizon are attributable to the presence of organic colloids as well as clay size material (Buckman and Brady, 1960). Horizons having low organic matter content have exchange capacity values that closely reflect the kind and amount of clay mineral present. The cation exchange capacity as determined by the summation of the exchangeable cation differs from that found directly by ammonium distillation. This difference reflects the removal of not only exchangeable cations but also some of the salts from the pore space in salt-bearing horizons. In such instances, cation thus removed may be better referred to as extractable cations. For the foregoing reason, exchangeable cations are reported in percentage of the cations exchange capacity as calculated by summation of the extractable cations, and may be expected to closely approximate the true values for exchangeable cations (Khan, 1967).

The National Soil Survey Committee (1965) defines soils of the Solonchic order as having a characteristic illuvial horizon with distinct morphological properties and a ratio of exchangeable calcium to exchangeable sodium of 10 or less. Most soils studied met these requirements.

The percentage distribution of exchangeable cations can be related to pedogenic development. The data (Tables XIV and XIV(a)) show that for the majority of the soils studied, the exchangeable calcium, magnesium, and hydrogen comprise the major portion of the exchangeable cations for all surficial horizons including the eluvial horizon. The

dominant exchangeable cations in the lower horizons consist of calcium, magnesium, and sodium. Generally, the percentage of exchangeable calcium increases with depth while the percentage of exchangeable magnesium and sodium consistently attains a maximum value in the illuvial horizon and then decreases with depth. The percentage of exchangeable hydrogen and pH reflects the extent of weathering that has occurred. The percentage of exchangeable potassium is generally highest in the upper horizons. This may be attributed to the acidic conditions prevailing in these horizons. Buckman and Brady (1961) reported that weathering of illite to montmorillonite under acidic conditions results in a considerable release of potassium ions.

The Solodic Dark Brown Chernozem at site 2 has a ratio of exchangeable calcium to exchangeable sodium greater than 10 and therefore is not included in the Solonetzic Order. This soil also has the lowest exchangeable magnesium content of all profiles studied. Exchangeable calcium increases while exchangeable hydrogen decreases with depth in the profile. The percentage distribution of the exchangeable cation as well as the pH of the upper horizons suggest that this soil has undergone solodization and is now acquiring chernozemic characteristics.

The Eroded Brown Solod at site 2 shows trends similar to those observed for the Solodic Dark Brown Chernozem although less pronounced. However, this profile has a solonetzic illuvial horizon still evident.

The Brown Solonetz (A) profile described at site 3 (Table XIV(a)) has a non-solonetzic illuvial horizon in which the ratio of exchangeable calcium to exchangeable sodium is greater than 10. However, this soil had distinct solonetzic morphology and very high percentage of exchangeable magnesium in its illuvial horizon. Bentley and Rost (1947) also reported

the presence of "magnesium solonetz" in Saskatchewan.

While sodium ions dominate the soluble salts extracted from the lower horizons of the Brown Solonetz and Brown Solod at site 1 as well as the Solodic Dark Brown Chernozem and Eroded Brown Solod at site 2, the exchangeable cation data show magnesium and calcium as dominating the exchange complex. This may be expected in view of the relative solubility of sodium sulfate as compared to that of magnesium and calcium sulfate. Ehrlich and Smith (1958) attributed similar results to the valence effect in the displacement of divalent calcium and magnesium ions by univalent sodium ion on the exchange complex. Another possibility mentioned is that a large quantity of sodium originally present in the exchange complex underwent gradual replacement by divalent cations that were not leached as rapidly as the sodium ions.

The Eroded Brown Solonetz at site 2 and the Brown Solonetz profiles at site 3 contain much larger quantities of soluble salts in the soil-water extracts from their lower horizons than the previous profile discussed. Moreover, magnesium is the dominant cation present in the soil-water extracts and occupies a large portion of the adsorption surface on the exchange complex.

(d) Calcium carbonate equivalent - The distribution of calcium carbonate equivalent with depth (Tables XIV and XIV(a)) in the profile generally follows a similar pattern for all profiles studied. The carbonate content increases with depth and attains a maximum value in the saline and/or carbonated horizons. The highest content of carbonate salts are found in the Brown Solonetz profiles at sites 1, 2, and 3. Similar results are reported by Bowser et al. (1962).

(e) Organic carbon, nitrogen, and carbon: nitrogen ratio -

The amount of organic carbon and nitrogen present in any soil has been related to the amount and degree of decomposition of its organic matter. Climate and vegetation or, more generally, ecological factors are known to affect the kind and amount of organic matter. The data (Tables XIV and XIV(a)) show that the organic carbon is highest in the surface horizons and decreases with depth. Organic carbon content of the C horizon is not reported since the amount determined is negligible. The organic nitrogen content follows a distribution pattern very similar to that of organic carbon. All Ah and Ahe horizons have C/N ratios well within the limit of 17 to 1 as defined by the Canadian Classification System (1965) for Chernozemic horizons. However, since some of the surface horizons are eroded, a few of the soils lack the minimum depth requirement for Chernozemic horizons.

(f) Dithionite extractable iron and aluminum - The data

presented in Tables XIV and XIV(a) show the dithionite extractable iron and aluminum content for all soils studied. The presence of dithionite extractable iron and aluminum is considered to be a measure of the amorphous and crystalline iron and aluminum oxides present in a soil (McKeague and Day, 1966) and has been related to dissolution of inorganic constituents. In general, content of extractable iron oxides remains constant or increases only slightly with depth while aluminum oxide content shows no definite trend. This is taken as an indication that there is little dissolution, if any, of mineral constituents to oxide forms. Arshad (1966) and Mathieu (1960) reported accumulation of extractable iron and aluminum oxides in the lower horizons.

3. Mineralogical Analyses

(a) Clay analyses - Semi-quantitative estimations of the composition of the total clay fraction were made by using X-ray diffraction data as well as chemical and physical analyses. All analyses were carried out on calcium saturated clays. Differential thermographs of the total and less than 0.2 micron clay fractions are presented in Figures 3 to 9. X-ray diffraction patterns of glycolated and heated (550°C.) clay samples for two size fractions are presented in Figures 10 to 16. Semi-quantitative estimates of the composition of the total clay fraction are presented in Tables XV and XV(a).

Estimates of the amount of illite and montmorillonite present in the total clay fraction were calculated on the basis of K₂O content, cation exchange capacities, and surface area. The amount of illite present in the total clay fraction was obtained by assigning all the potassium to illite and assuming illite to have a K₂O content of 10 per cent (Mehra, 1959). The illite thus calculated was assigned a cation exchange capacity of 20 me./100 g. and a surface area of 10 m²/g. The contribution of illite to the total cation exchange capacity and surface area was subtracted and the difference was attributed to montmorillonite, assuming this mineral to have a cation exchange capacity of 90 me./100 g. and a total surface area of 980 m²/g. St. Arnaud and Mortland (1963) have used similar values to study the clay mineralogy of similar soils in Saskatchewan. The amount of montmorillonite was thus calculated by two methods. An estimation of the amount of quartz present in the total clay fraction was made on the basis of X-ray diffractograms. X-ray diffractograms were also utilized to obtain qualitative information on the structure of various clay minerals.

TABLE XV. MINERALOGICAL COMPOSITION OF TOTAL CLAY FRACTION

| Hor. | Total C.E.C. me./100 g. | Surface Area m ² /g. | K ₂ O % | Mont. (1) % | Mont. (2) % | Mont. Mean % | Illite % | Quartz* % | Others** % |
|---|-------------------------------|---------------------------------------|-----------------------|-------------------|-------------------|--------------------|-------------|--------------|---------------|
| Classification: Brown Solonetz (Site 1) | | | | | | | | | |
| Ah | 40.9 | 484 | 3.02 | 39 | 48 | 44 | 30 | 10-15 | 13 |
| Ae | 31.7 | 206 | 2.76 | 29 | 21 | 25 | 28 | 15-25 | 27 |
| Bnt | 53.5 | 658 | 2.70 | 54 | 66 | 60 | 27 | <5 | 10 |
| C ₁ | 51.1 | 568 | 2.18 | 53 | 57 | 55 | 22 | <5 | 20 |
| Classification: Brown Solod (Site 1) | | | | | | | | | |
| Ah | 39.9 | 465 | 2.40 | 39 | 47 | 43 | 24 | <5 | 30 |
| Ae | 20.0 | 175 | 3.56 | 14 | 18 | 16 | 36 | 20-25 | 25 |
| Bnt | 45.0 | 559 | 2.61 | 45 | 56 | 51 | 26 | <5 | 20 |
| C ₁ | 51.5 | 538 | 2.40 | 52 | 54 | 53 | 24 | <5 | 20 |
| Classification: Solodic Dark Brown Chernozem (Site 2) | | | | | | | | | |
| Ahe | 36.6 | 454 | 2.19 | 36 | 45 | 41 | 22 | 5-10 | 29 |
| Bt | 52.8 | 616 | 1.95 | 55 | 62 | 59 | 20 | <5 | 18 |
| Cca | 65.1 | 704 | 1.01 | 71 | 70 | 71 | 10 | <5 | 16 |
| Classification: Eroded Brown Solod (Site 2) | | | | | | | | | |
| Ahe | 51.4 | 632 | 2.11 | 53 | 63 | 58 | 21 | 5-10 | 13 |
| Bnt | 57.2 | 654 | 1.27 | 61 | 65 | 63 | 13 | <5 | 21 |
| C | 59.8 | 603 | 1.34 | 64 | 60 | 62 | 13 | <5 | 22 |

* Estimates based on X-ray diffraction patterns.

** Includes chlorite, kaolinite, and amorphous materials.

(1) Montmorillonite values based on cation exchange capacity data.

(2) Montmorillonite values based on surface area data.

TABLE XV(a). MINERALOGICAL COMPOSITION OF TOTAL CLAY FRACTION

| Hor. | Total C.E.C. me./100 g. | Surface Area m ² /g. | K ₂ O % | Mont. (1) % | Mont. (2) % | Mont. Mean % | Illite % | Quartz* % | Others** % |
|--|-------------------------------|---------------------------------------|-----------------------|-------------------|-------------------|--------------------|-------------|--------------|---------------|
| Classification: Eroded Brown Solonetz (Site 2) | | | | | | | | | |
| Ae | 48.0 | 479 | 2.35 | 49 | 48 | 49 | 24 | <5 | 24 |
| Bnt | 60.5 | 712 | 2.09 | 63 | 71 | 67 | 21 | <5 | 9 |
| Csaca | 58.0 | 610 | 1.47 | 62 | 61 | 62 | 15 | <5 | 20 |
| Classification: Brown Solonetz (A) (Site 3) | | | | | | | | | |
| Ae | 45.9 | 457 | 2.05 | 47 | 46 | 47 | 21 | 5-10 | 24 |
| Bnt | 55.4 | 537 | 2.60 | 56 | 54 | 55 | 26 | <5 | 16 |
| C | 48.6 | 456 | 1.60 | 51 | 46 | 49 | 16 | <5 | 32 |
| Classification: Brown Solonetz (B) (Site 3) | | | | | | | | | |
| Ae | 39.2 | 434 | 1.82 | 40 | 43 | 42 | 18 | <5 | 35 |
| Bnt ₁ | 53.7 | 529 | 1.47 | 57 | 53 | 55 | 15 | <5 | 27 |
| Bnt ₂ | 52.2 | 476 | 1.64 | 55 | 48 | 52 | 16 | <5 | 29 |
| Csk | 47.7 | 507 | 1.58 | 50 | 51 | 51 | 16 | <5 | 30 |

*Estimates based on X-ray diffraction patterns.

** Includes chlorite, kaolinite, and amorphous materials.

(1) Montmorillonite values based on cation exchange capacity data.

(2) Montmorillonite values based on surface area data.

As indicated in Tables XV and XV(a), the total exchange capacity of the total clay fraction is lowest in the eluvial horizon and highest in the B and/or C horizons. The clays from the illuvial horizons do not show higher C.E.C. as expected on the basis of their greater proportion of fine clay material. This may be attributed to the presence of higher amounts of illite material in the B horizons than in the C horizons.

The surface area data shows essentially the same trends as the cation exchange capacity results. The comparatively high surface area of the clays from the Ahe horizon of the Eroded Brown Solod at site 2 is thought to be attributable to the presence of colloidal organic matter in the clay fraction.

The percentage of K_2O in the total clay fraction is highest in the eluvial horizons, lower in the illuvial horizons, and least in the C horizons. Higher K_2O percentage in the eluvial horizons as compared to the illuvial horizons suggests that preferential movement of montmorillonite over illite occurs during pedogenesis. These findings are substantiated by X-ray diffractograms for the total clay fraction which show greater amounts of illite in the eluvial horizons as compared to the illuvial horizons. However, the fact that the K_2O percentage in the total clay fraction from the illuvial horizons is higher than that from the C horizons either negate the foregoing possibility of preferential translocation of montmorillonite to the B horizons or indicates the possibility of illitization. The data seem to favor the latter possibility. Evidence for illitization of montmorillonite has been reported by St. Arnaud and Mortland (1963) as well as by Winters and Simonson (1951).

Tables XV and XV(a) show the montmorillonite content calculated

from the surface area data to be generally somewhat higher than that calculated from the cation exchange capacity data. However, these differences are generally within the error of experimental procedures for the two methods of analyses.

The per cent of quartz was estimated from the X-ray diffractograms of the total clay fraction on the basis of the intensity of the 4.21 \AA ($21^{\circ} 2 \theta$) peak. As shown in Tables XV and XV(a), the estimated quartz content of the total clay fraction varied from less than 5 per cent to as much as 15 to 25 per cent. The fine grained quartz content of the total clay fraction is highest in the eluvial horizons and somewhat lower in the B and C horizons. X-ray diffractograms (Figures 10 to 16) indicate that the profiles at site 1 have the largest amount of quartz present in the total clay fraction. St. Arnaud and Whiteside (St. Arnaud and Mortland, 1958) reported that the accumulation of fine grained quartz in the coarse clay fraction of solum horizons is indicative of weathering which may largely result from a process of physical breakdown of coarser particles to clay size. Presence of larger quantities of quartz in the coarse clay fraction of the profiles at site 1 corroborates other data indicating that weathering has resulted in a breakdown of soil material into finer sized units.

Unidentified clay material accounts for 9 to 35 per cent of the total clay fraction (Tables XV and XV(a)). It is assumed that the unidentified portion of the clay fraction consists essentially of chlorite, kaolinite, and amorphous material. The percentage of such clay material is generally highest in the eluvial horizons and decreases markedly in the illuvial horizons. These findings are in accordance with the expected

increase in amounts of amorphous silica present in the eluvial horizons of Solonetzic soils as a result of solodization (Joffe, 1949). Mathieu (1960) reported degradation of chlorite and montmorillonite in the coarse clay fraction of Ae horizons of Solodized Solonetz soils and indicated that the degraded clay may appear in the fine clay fraction.

Both the total and less than 0.2 micron clay fractions were calcium saturated prior to glycolation and heating at 550°C. for two hours. The X-ray diffraction patterns (Figures 10 to 16) suggest the clay mineralogy of the parent material for the two profiles at site 1 to be very similar. All profiles at sites 2 and 3 also have very similar clay mineral distribution in their parent material. The parent materials at these sites (2 and 3) have lesser quantities of illite and greater quantities of well defined montmorillonite than the parent material at site 1.

Upon glycol solvation, both the fine and total clay fractions show 17\AA° peaks that are broad and ill-defined in the A horizons, sharper in the B horizons, and sharpest in the C horizons. The broad and ill-defined peaks for clays from the Ah and Ae horizons suggest the presence of chlorite-montmorillonite interlayering and/or chloritization. Mathieu (1960) reported similar results in a study of some Saskatchewan Solonetzic soils. The poorly defined and broad peaks for clays in the Ah horizons can also be attributed to the presence of organic constituents which prevent maximum glycolation and/or to the possibility of illite weathering to montmorillonite (White, 1951).

The generally broad and intense 17\AA° - 18\AA° peaks for the clays from the B horizons suggest the presence of minerals with some interlayering. Sharp and well defined 17\AA° peaks for clays from C horizons of all

profiles investigated indicate the presence of relatively unweathered clay minerals.

The Brown Solonetz and Brown Solod profiles at site 1 show the greatest evidence for montmorillonite degradation in the A horizons. This is indicated by the broadness of the 17\AA° to 18\AA° (glycol solvated) peak.

The X-ray diffractograms of the less than 0.2 micron clay fraction show characteristics essentially similar to those of the total clay fraction. However, the less than 0.2 micron clay fraction generally shows sharper 17\AA° peaks. This is attributed to the higher proportion of montmorillonite in this finer clay fraction and/or to the greater amount of interlayered clay minerals in the total clay fraction.

Upon heat treatment, montmorillonite collapses to a 10\AA° ($8.8^{\circ}2\theta$) spacing but, as indicated in Figures 10 to 16, the 10\AA° line trails off toward the $17 - 18\text{\AA}^{\circ}$ peaks and suggests the possible presence of low quantities of montmorillonite-chlorite clay minerals. This effect is particularly pronounced in the clays from the Ah horizons from the profiles at site 1 as well as from the Ahe and Ae horizons of the profiles at sites 2 and 3.

Appearance of a reflection line at 7.2\AA° (12.4°) in the glycolated total clay samples is attributable to either first order kaolinite reflection or second order chlorite and/or vermiculite reflection. Persistence of the 7.2\AA° peak following a heat treatment at 550°C . excludes the possibility of the presence of kaolinite. However, some varieties of chlorite minerals may also collapse upon heat treatment but a 14\AA° peak usually persists. Moreover, no satisfactory method exists for the distinction between the presence of chlorite and kaolinite with absolute certainty.

The 7.2\AA° reflections are generally most intense in the eluvial horizon, less in the C horizon, and least in the B horizon. The less than 0.2 micron clay fraction shows slightly less intense 7.2\AA° peaks. The general lack of a well developed 14\AA° peak suggests that kaolinite is largely responsible for the 7.2\AA° diffraction line.

The X-ray diffractogram indicates montmorillonite and illite to be the dominant clay minerals in the soils studied. Evidence of montmorillonite interlayering is indicated by the broadness of its 17\AA° peak after glycolation as well as by the broadness of the 10\AA° peak obtained by heating the samples at 550°C . for two hours. Soils at site 1 show the most poorly defined montmorillonite as well as the largest amount of clay size quartz. This further suggests that the Brown Solonetz and Brown Solod soils at site 1 have undergone the greatest degree of weathering of all profiles studied. X-ray diffractograms (Figures 10 to 16) suggest that a significant amount of quartz is present in the total clay fraction. Jackson (1956) has also reported that quartz and feldspars are not likely to be present in the fine clay fraction. The less than 0.2 micron clay mineral fraction produced sharper glycolated montmorillonite peaks, perhaps reflecting its higher content.

Differential thermograms for calcium saturated clay fractions are presented in Figures 3 to 9. Differential thermal analyses provide additional evidence needed to effectively substantiate information obtained from X-ray analyses and chemical analyses. The low temperature endothermic peaks occurring between 120 and 240°C . are the result of the loss of interlayer water and reflect only differences in hydration of the clay. While Mathieu (1960) reported that identification of the clay

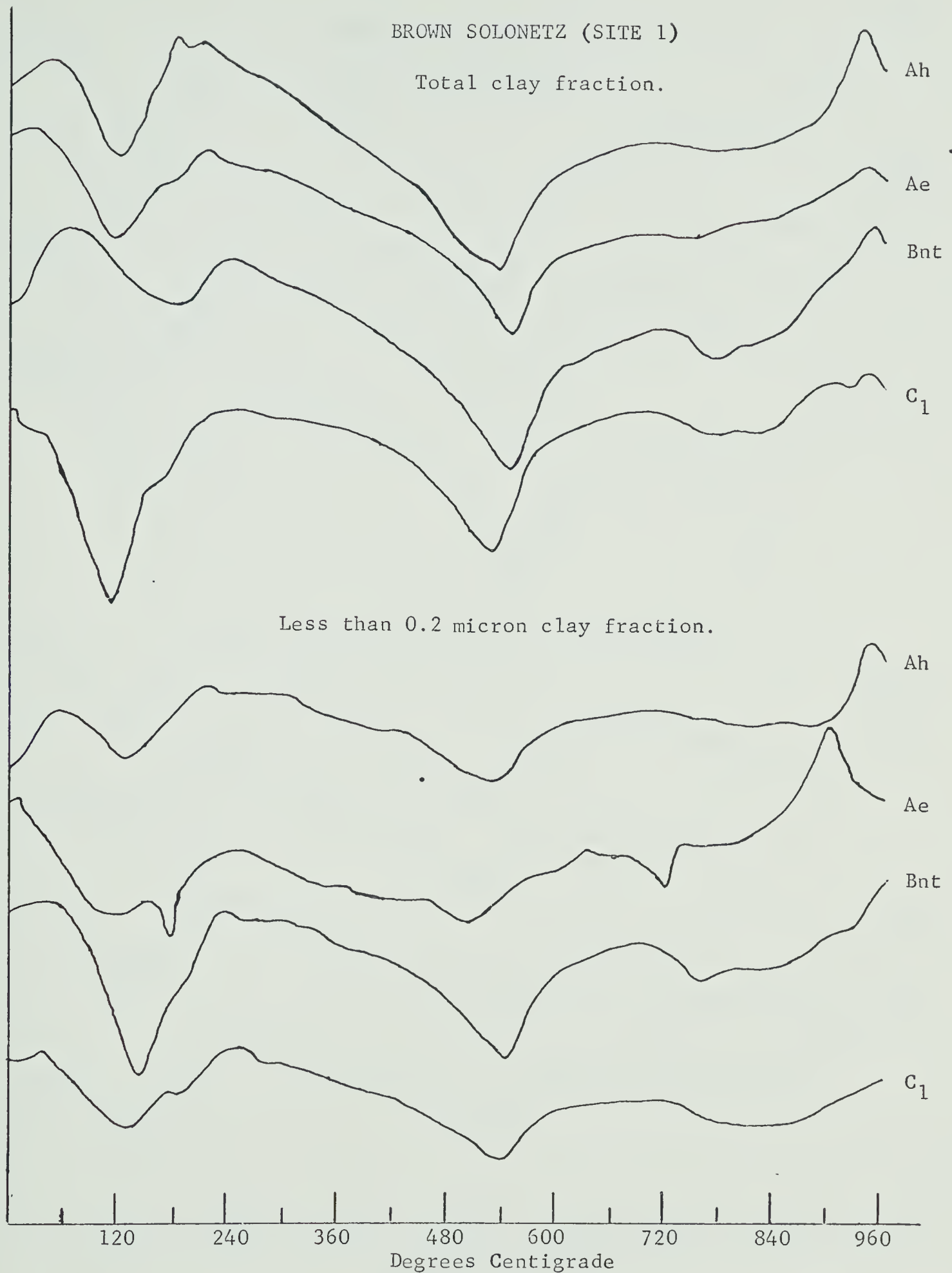


Figure 3. Differential thermographs of the total and less than 0.2 micron clay fractions.

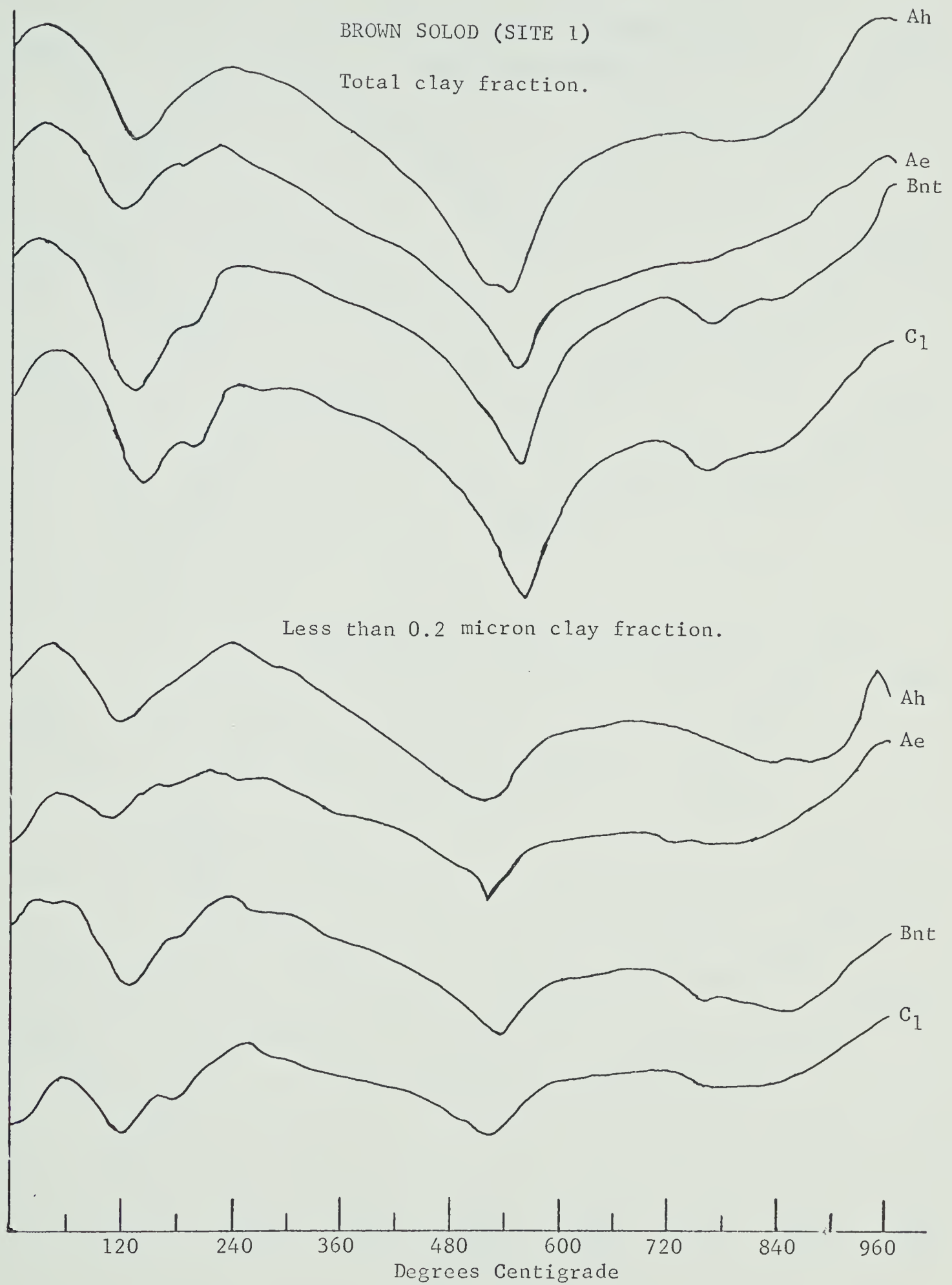


Figure 4. Differential thermographs of the total and less than 0.2 micron clay fractions.

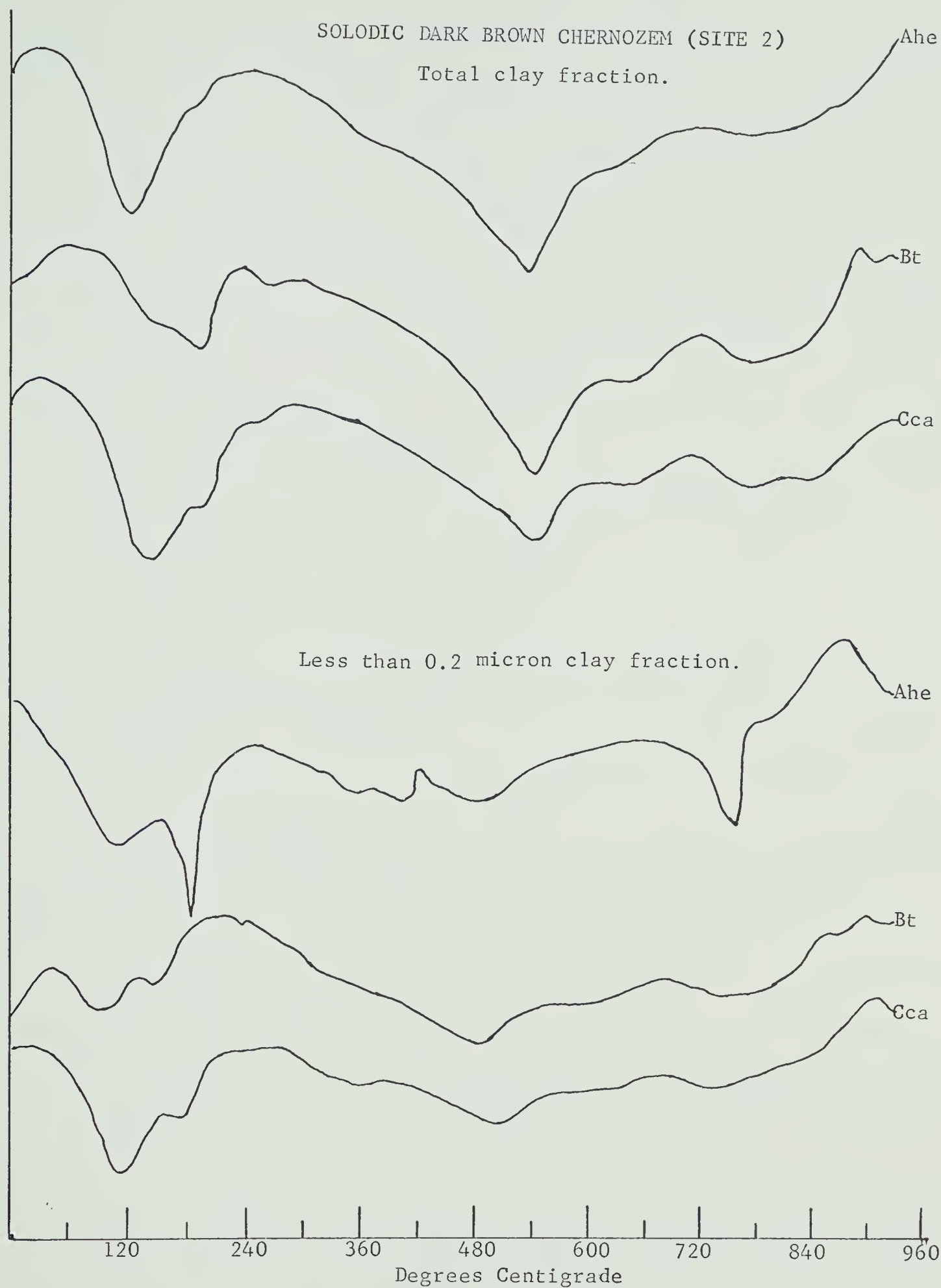


Figure 5. Differential thermographs of the total and less than 0.2 micron clay fractions.

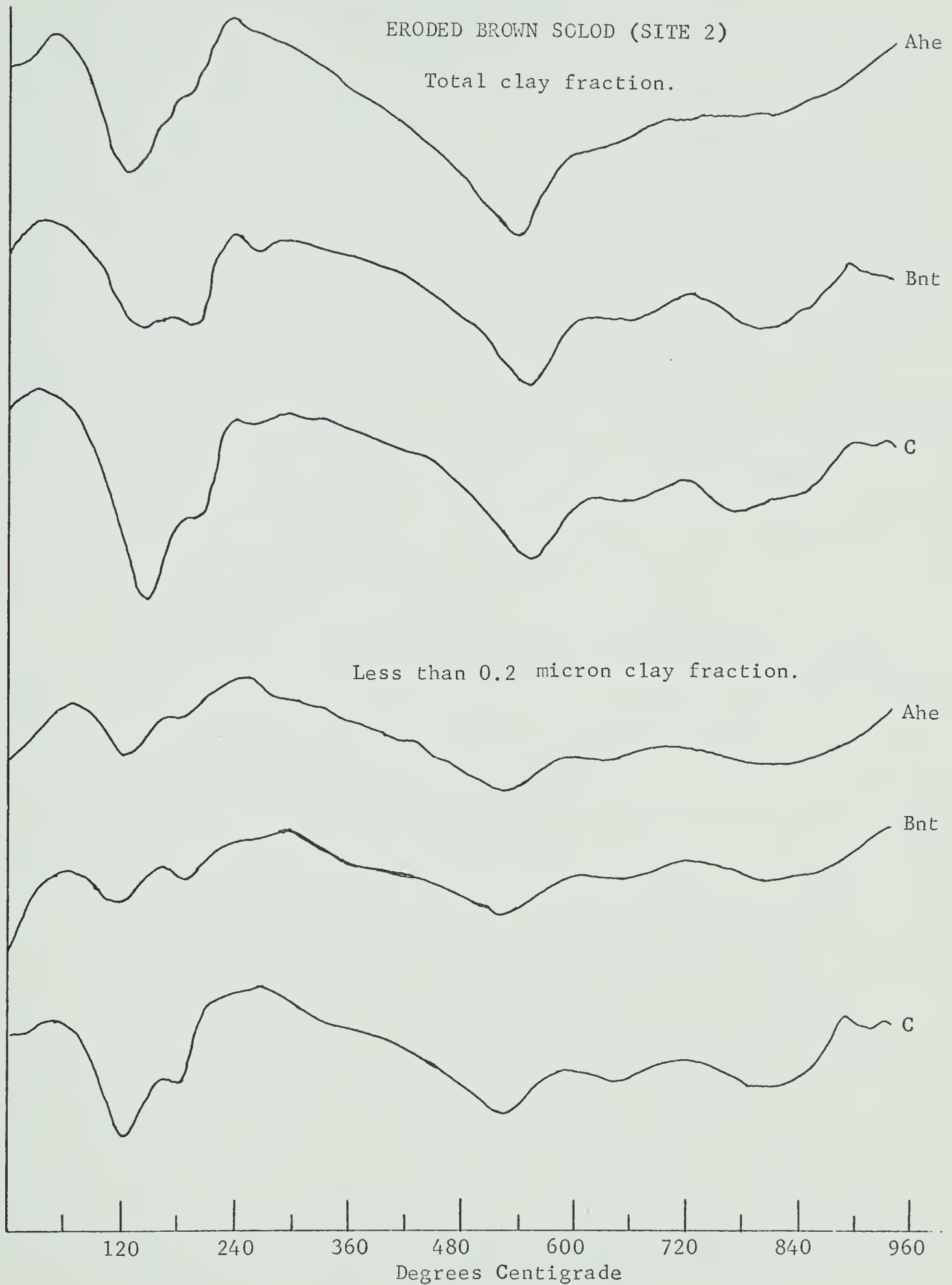


Figure 6. Differential thermographs of the total and less than 0.2-micron clay fractions.

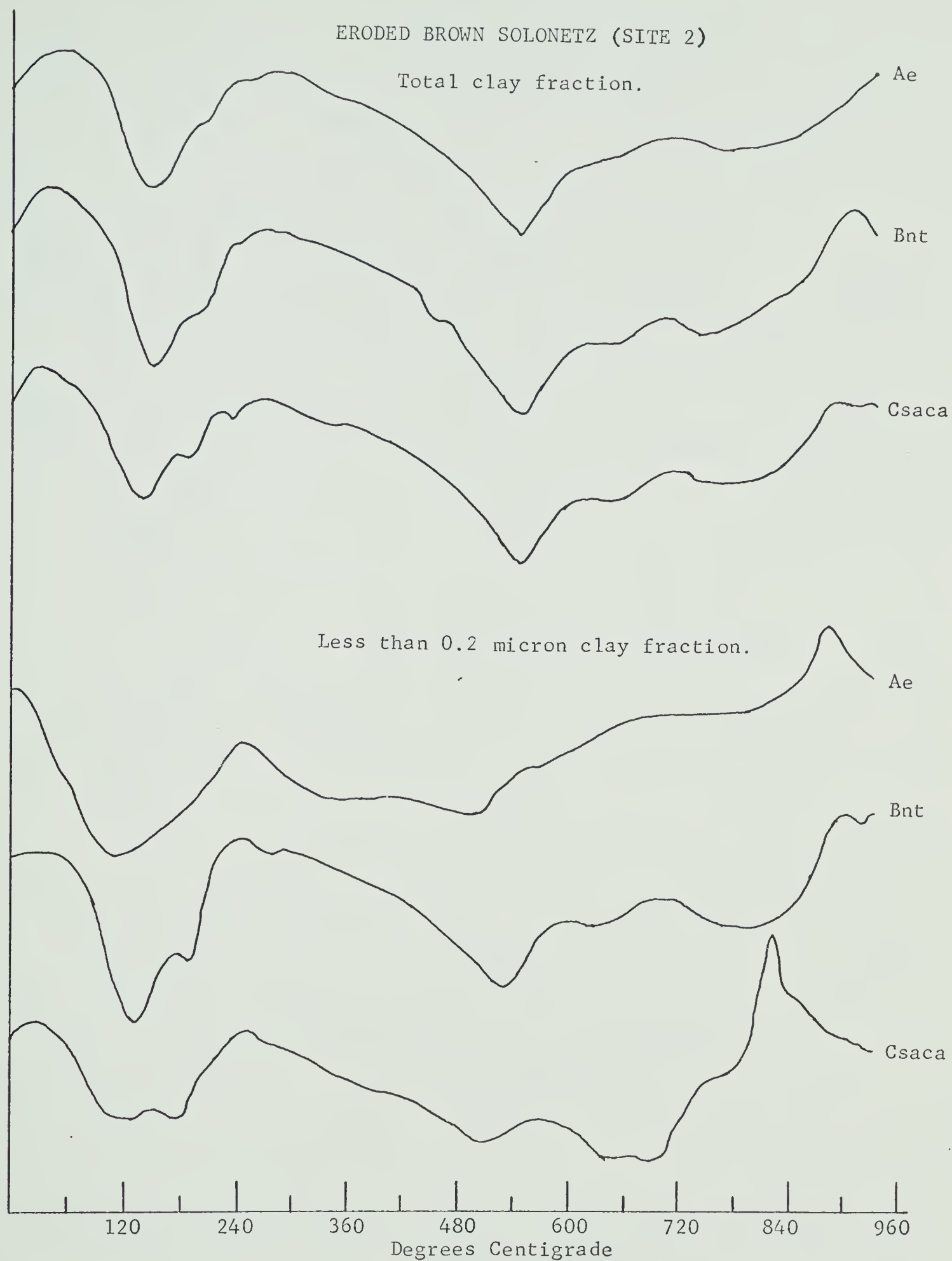


Figure 7. Differential thermographs of the total and less than 0.2 micron clay fractions.



Figure 8. Differential thermographs of the total and less than 0.2 micron clay fractions.

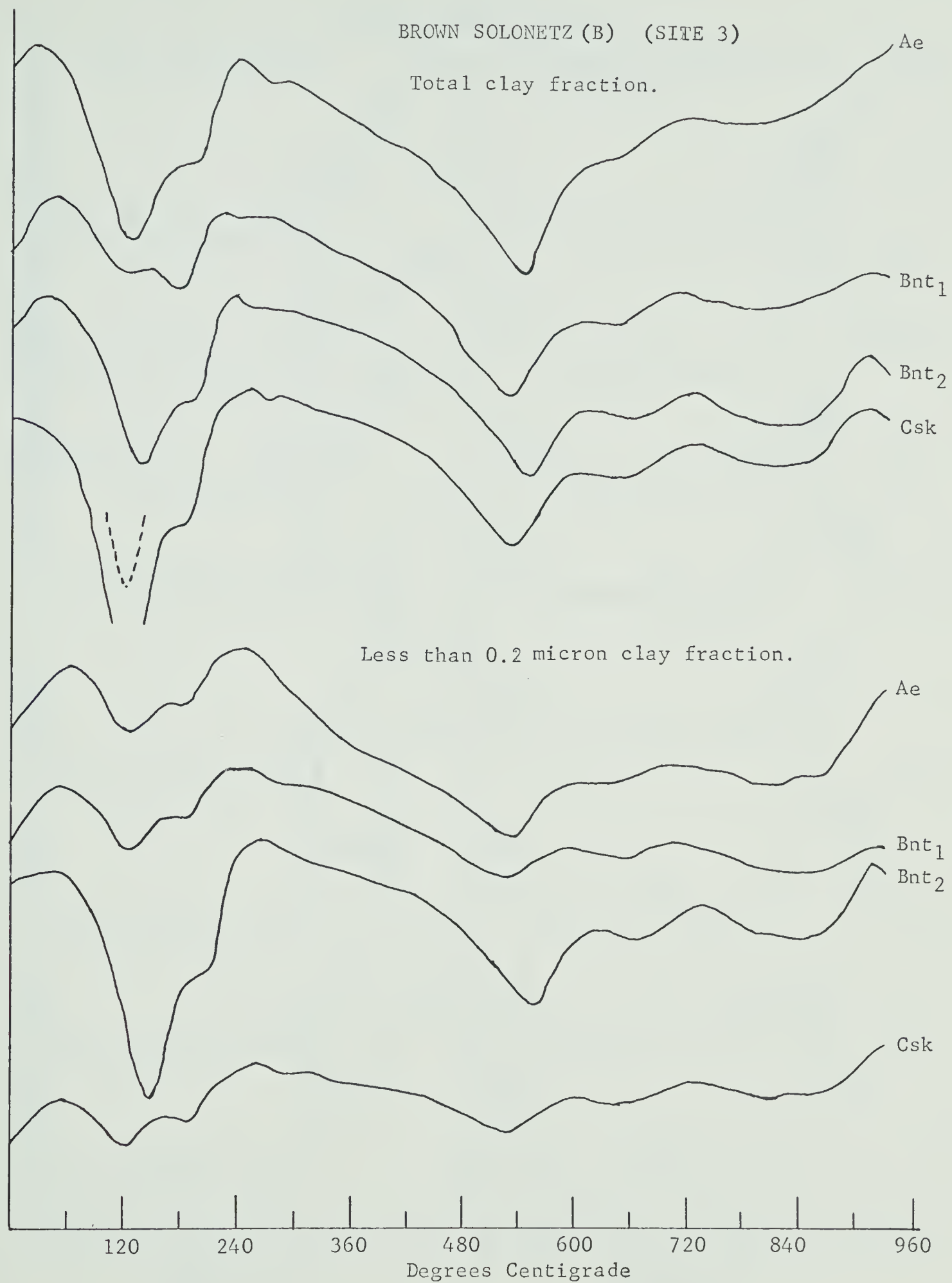


Figure 9. Differential thermographs of the total and less than 0.2 micron clay fractions.

BROWN SOLONETZ (SITE 1)

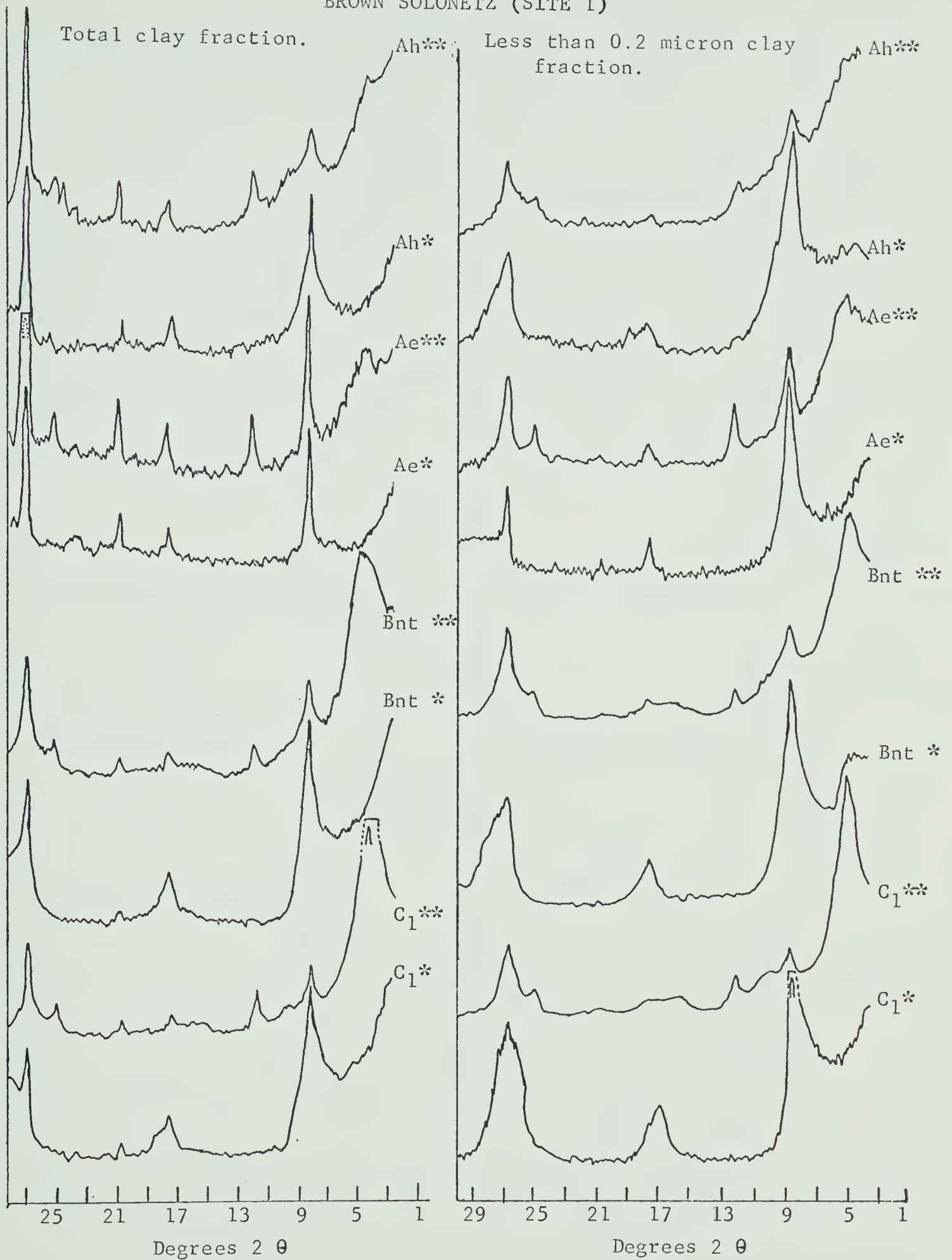


Figure 10. X-ray diffraction patterns of total and less than 0.2 micron clay fractions, heated* and glycolated.**

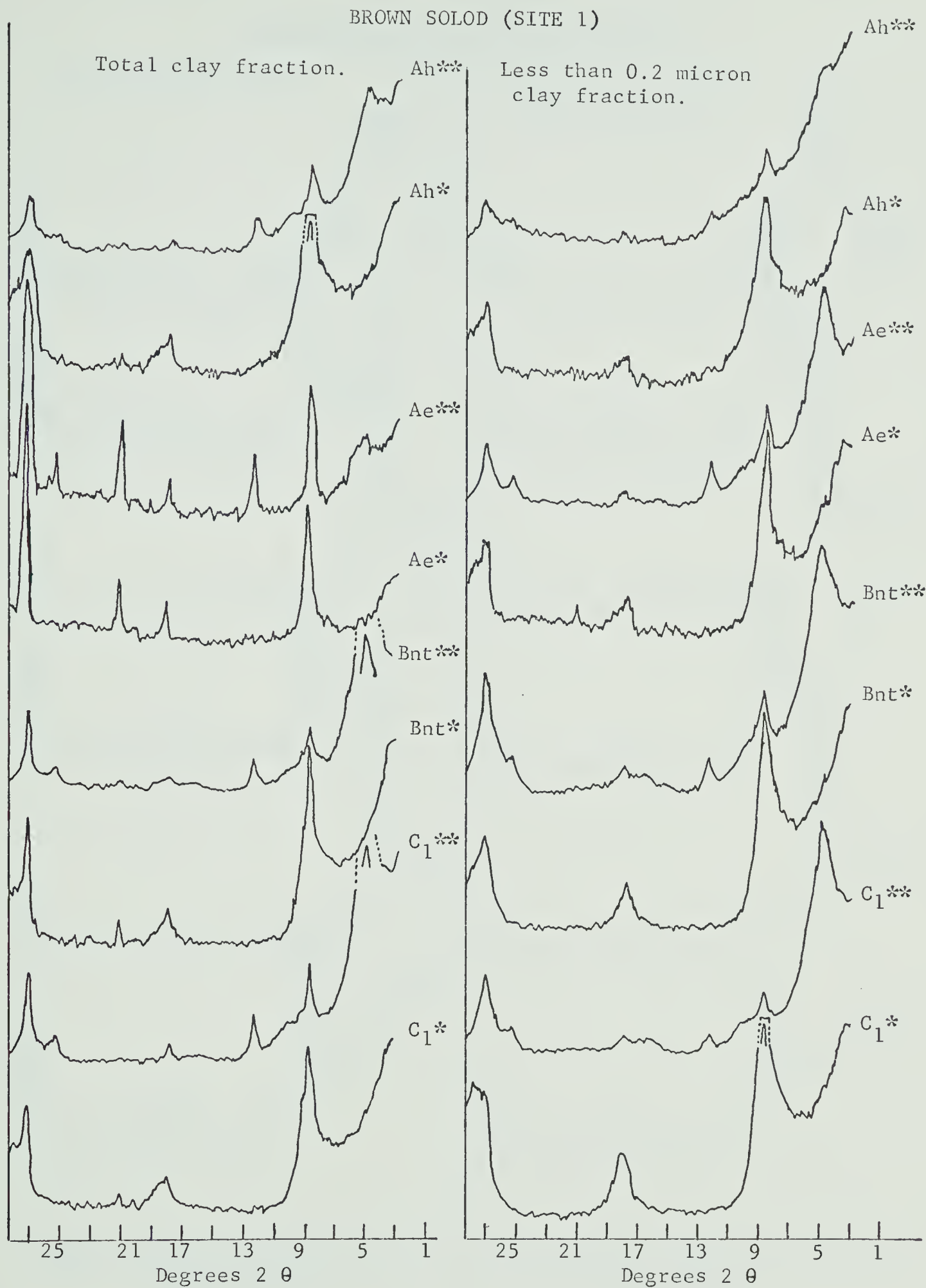


Figure 11. X-ray diffraction patterns of total and less than 0.2 micron clay fractions, heated* and glycolated.**

SOLODIC DARK BROWN CHERNOZEM (SITE 2)

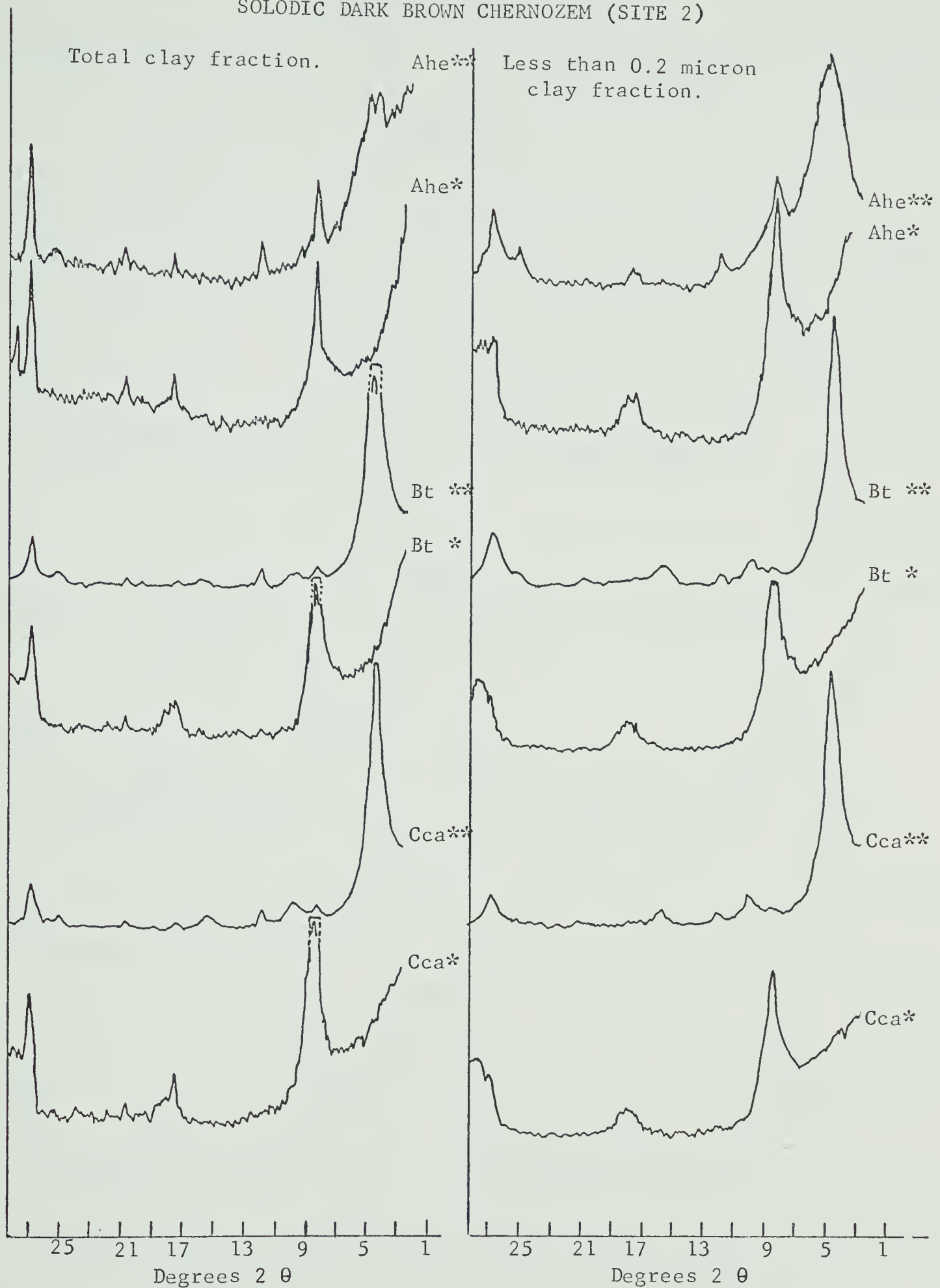


Figure 12. X-ray diffraction patterns of total and less than 0.2 micron clay fractions, heated* and glycolated.**

ERODED BROWN SOLOD (SITE 2)

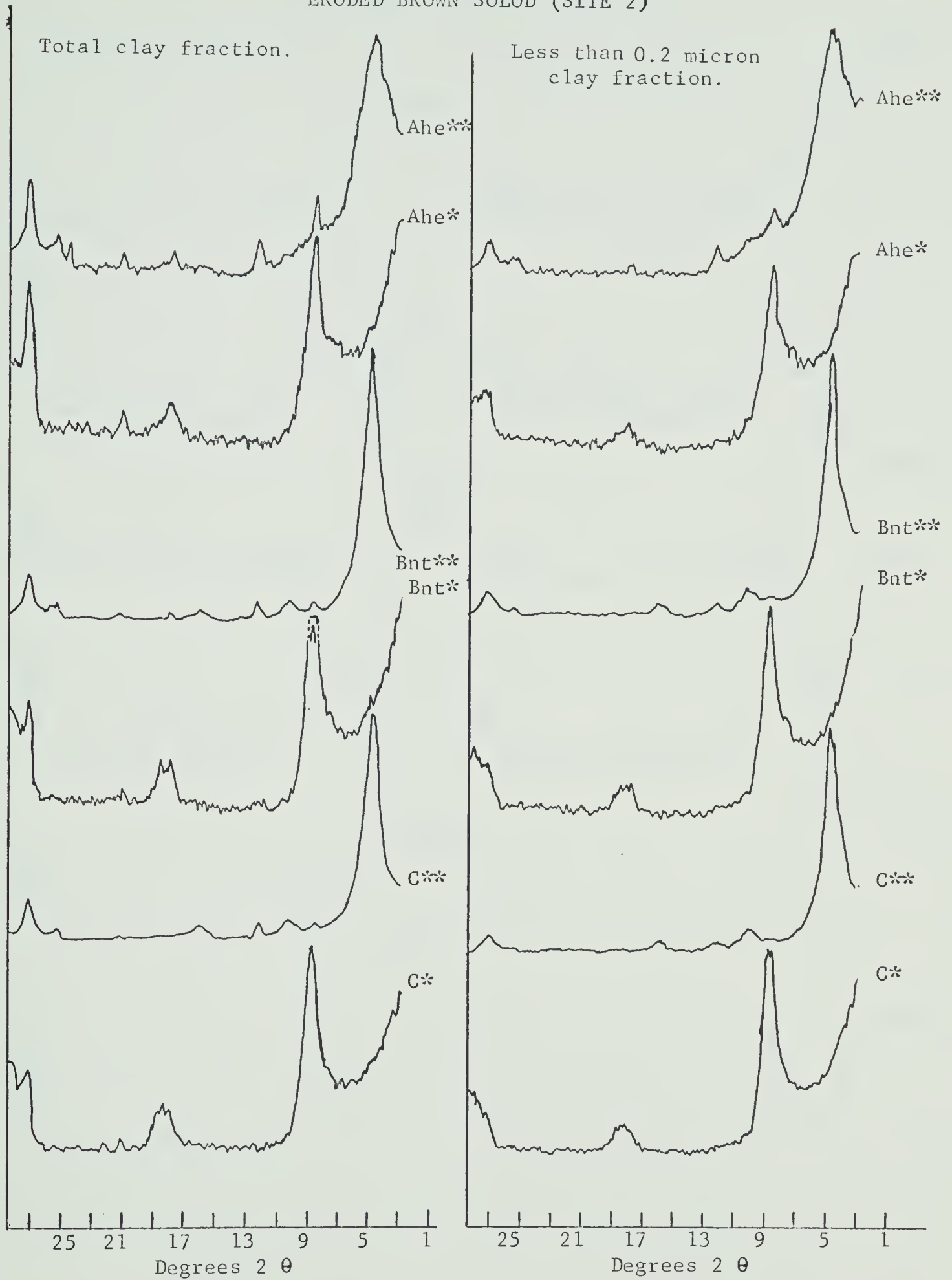


Figure 13. X-ray diffraction patterns of total and less than 0.2 micron clay fractions, heated* and glycolated.**

ERODED BROWN SOLONETZ (SITE 2)

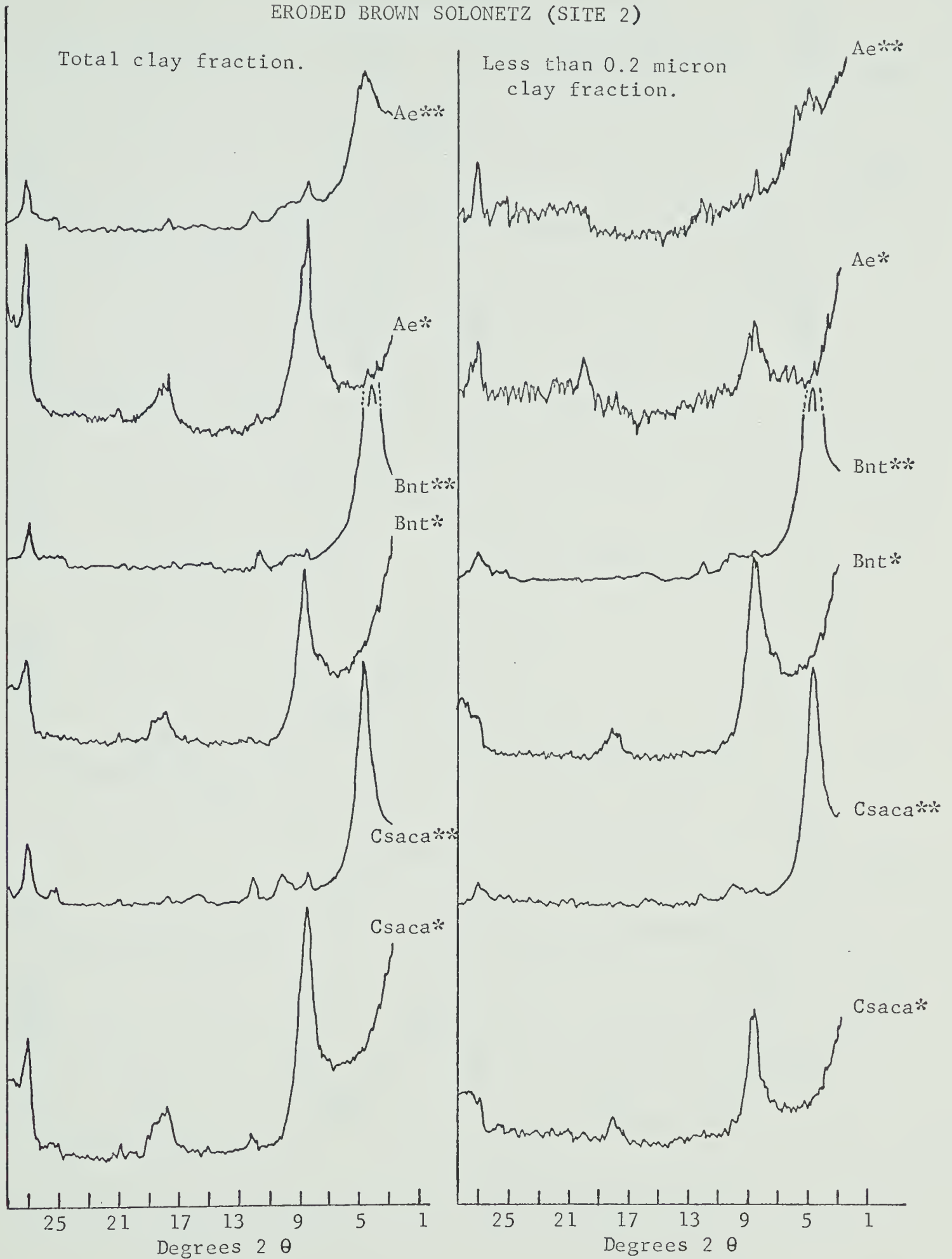


Figure 14. X-ray diffraction patterns of total and less than 0.2 micron clay fractions, heated* and glycolated.**

BROWN SOLONETZ (A) (SITE 3)

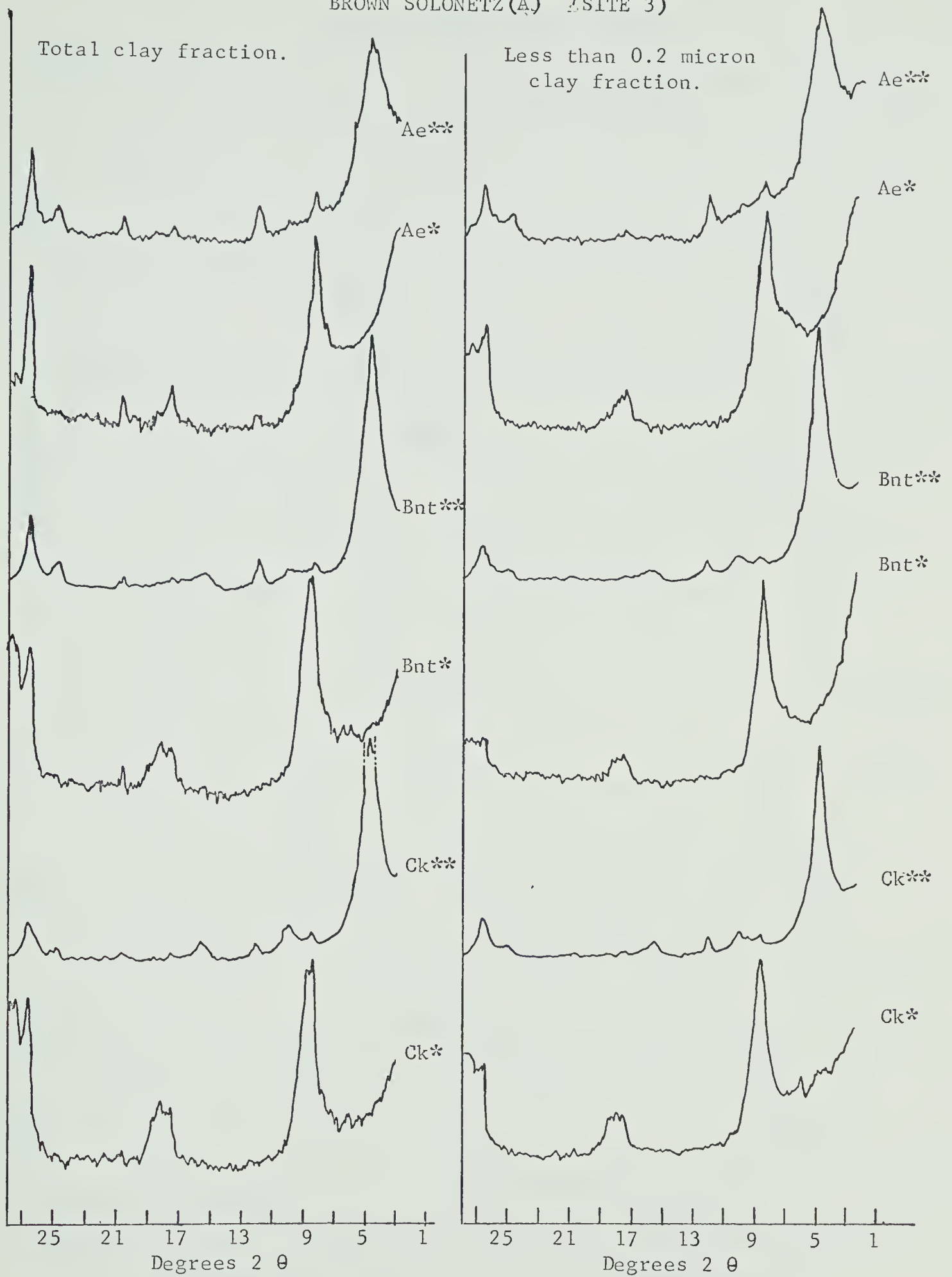


Figure 15. X-ray diffraction patterns of total and less than 0.2 micron clay fractions, heated* and glycolated.**

BROWN SOLONETZ (B) (SITE 3)

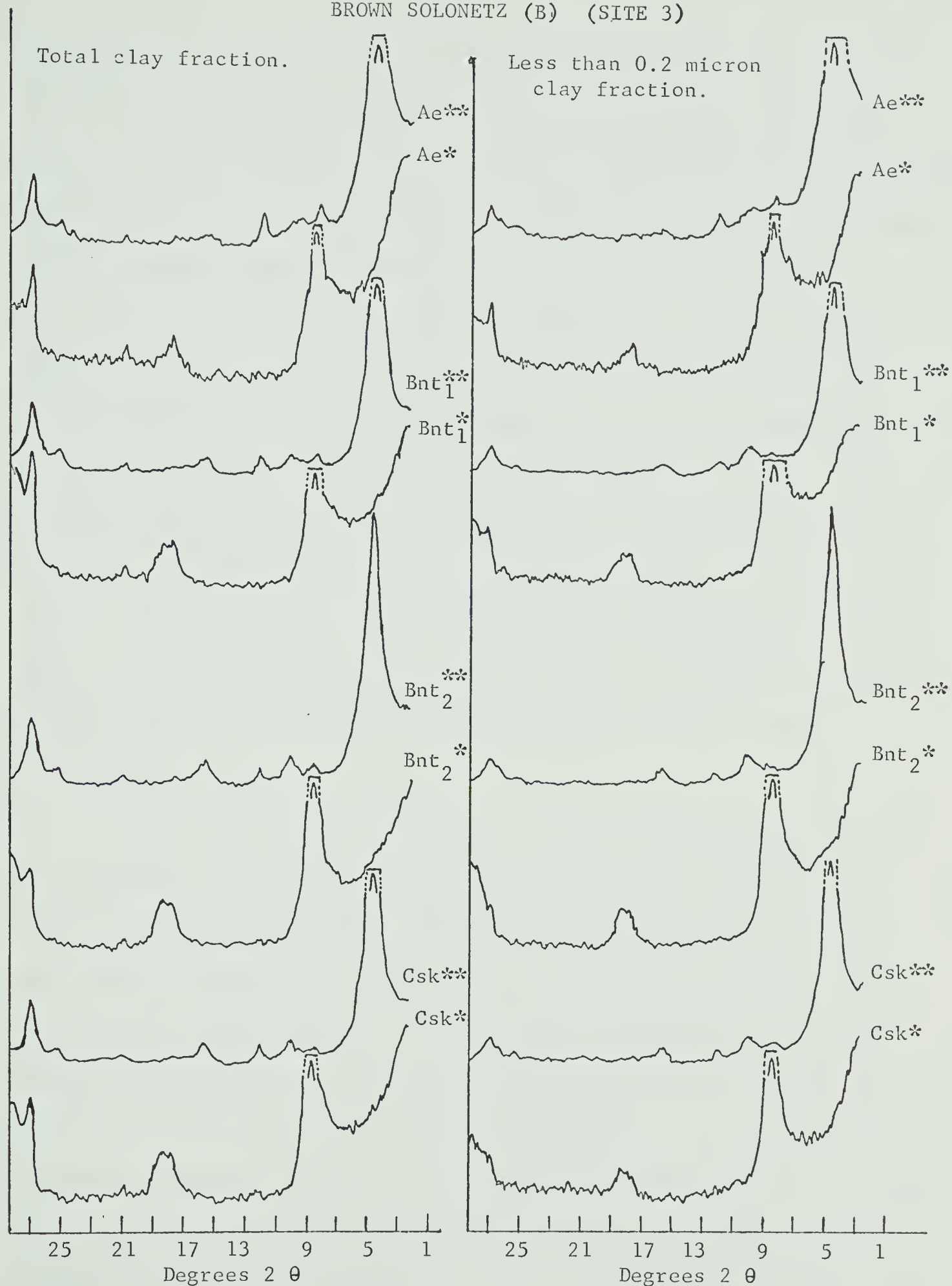


Figure 16. X-ray diffraction patterns of total and less than 0.2 micron clay fractions, heated* and glycolated.**

minerals from thermal data rests solely on the shape and intensity of the midrange endothermic loop, the use of low temperature endothermic peaks for mineral identification is also of considerable importance (Greene-Kelley, 1966). The thermographs have strong hydroxyl endotherms between 500°C. and 590°C. which is typical of illitic minerals. However, St. Arnaud (1963) and Kodama et al. (1965) have shown that "abnormal montmorillonite" also shows peaks in the same temperature range. As shown in Figures 3 to 9, the temperature at which the hydroxyl endothermic peaks occur generally increases with depth in the soil. This indicates that disintegration or degradation of clay minerals increases from the C horizon to the A horizon. Such conclusions are based on the work of Rowland (Mathieu, 1960) who postulated that structural disintegration is associated to lower relative energies. Consequently, lower thermal energies are required for dehydroxlation of such crystal structures.

(b) Light mineral analyses - Mineralogical composition of the fine sand fraction of specific gravity less than 2.70 g./cc. is given in Tables XVI to XVIII. Elemental analyses data were used to calculate the percentage of potassium and soda-calcic feldspars. The percentage of quartz was found by difference. Results show that the quartz percentage varies between 60 to slightly over 80 per cent, the distribution of which largely reflects variability in the composition of parent material among the three sites rather than intensity of pedogenic development. It is unlikely that measured quartz percentages reflect weathering of the mineral fraction as indicated from the apparent increase in quartz with depth in the profiles at site 1. Quartz

percentages in the fine and very fine sand fractions of soils at sites 2 and 3 are slightly higher in the upper horizons. Since quartz is a mineral more stable than the feldspars, this increase could possibly be attributed to negative enrichment. However, as reported in the "Physical Analyses" section of this discussion, disintegration of feldspar-bearing rocks may have contributed to the feldspar content in the weathered horizons and thus altered the distribution pattern of quartz throughout the soil profile.

The percentage of soda-calcic feldspars is consistently higher than the potassium feldspar. The comparison of distribution for the potassium and soda-calcic feldspars with depth (profiles at sites 2 and 3) indicates that soda-calcic feldspars have weathered to a greater extent than potassium feldspars in the soils sola. Arshad (1964) reported similar results for Solonetzic soils of Alberta.

4. Evaluation of Soil Development

(a) Introduction - Soil development results, among other things in the differentiation of the soil solum into horizons. The processes responsible for the transformation of the solum are best studied when a quantitative measure of profile development can be introduced. Marshall and Haseman (1942) were among the first soil scientists to outline a method providing a quantitative measure for some changes resulting from soil formation. Barshad (1964) outlined detailed procedures for the evaluation of soil development by both mineralogical and chemical means. He stated that soil formation resulted essentially from:

- (a) depletion from the profile (drainage, water leaching, soluble elements);
- (b) transformation within the profile (clay minerals, organic matter); and

(c) additions to the profile (atmospheric water, etc.). Barshad (1964), in outlining his method, considered the nonclay fraction of the soil to be the reactant and the clay fraction to be the product of pedogenesis. His method evaluates the degree of soil evolution by comparing the present properties of the soil material at each horizon with what is believed to be the original soil parent material.

The task of evaluating soil development is considerably easier for soils developed from homogeneous parent material since, in such cases, it is reasonably certain that the characteristics and properties of the underlying parent material is representative of the original parent material from which the soil has developed. Thus, one of the most important steps involved in evaluating profile development is to establish the initial state of the soil material at each position of the profile. Once the initial state is established, soil development can be measured in terms of the change in physical, chemical, and mineralogical properties that have occurred during the transformation of the parent material into a soil body. Since the method proposed by Barshad (1964) depends upon the assumption that clay is formed from the nonclay fraction, profile development can be correlated to the change in the absolute amount of any significant soil material present in a given horizon as determined by the absolute amount (weight) of a selective index mineral present in that horizon.

An index mineral can be defined as a portion of soil material (generally a mineral) that is very resistant to weathering and that is immobile, consequently of nonclay size.

The calculations involving index mineral weight are best carried out on a soil volume basis. The soil volume of each horizon is calculated

by multiplying the depth of the horizon by a unit surface area (usually 1 cm.²). Thus, the weight of any given soil material originally present in any horizon can be calculated by relating the weight of index mineral present in the horizon to the weight of the same index mineral in a given volume of parent material. Changes resulting from soil development can thus be measured.

(b) Evaluation of parent material uniformity - Barshad (1964) outlined various techniques that may be used to establish the degree of uniformity of the parent material from which the soil profile has developed. The most valuable criteria that this author has suggested for establishing the uniformity of a given parent material are: (a) the "nature of the ratio of two resistant minerals in any one fraction of the nonclay fraction, preferably the fine sand or coarse silt", and (b) "The nature of particle-size distribution of the resistant minerals -- either the heavy or the light -- of the nonclay fraction".

The latter criterion was chosen to establish the uniformity of the original parent material. This method is based on the principle that, since the resistant minerals are not significantly weathered during the course of soil formation, their particle-size distribution pattern should remain undisturbed. Consequently, if the particle-size distribution of a resistant mineral in various size fractions remains constant, it indicates that the soil is formed from a uniform parent material.

The percentage of quartz (index mineral) in the fine sand and very fine sand fraction of all soils studied is reported in Tables XVI to XVIII. The results suggest that the percentage of quartz in the very fine sand fraction is slightly lower than that in the fine sand fraction. However, the relatively constant value obtained for the ratio of quartz

TABLE XVI. EVALUATION OF PARENT MATERIAL UNIFORMITY (SITE 1)

| Hor. | Nonclay % | Fine Sand Fraction | | | Quartz ³ in V.F.S. % | % Quartz in F.S. |
|--------------------------------|--------------|---|---|--------------------------|---------------------------------------|--------------------|
| | | Potassium ¹ Feldspar % | Soda-Calcic ² Feldspar % | Quartz ³ % | | % Quartz in V.F.S. |
| Classification: Brown Solonetz | | | | | | |
| Ah | 82 | 9.3 | 15.9 | 74.8 | 70.5 | 1.06 |
| Ahe | 87 | 9.0 | 16.2 | 74.8 | 70.0 | 1.07 |
| Ae | 92 | 9.3 | 16.2 | 74.5 | 65.4 | 1.14 |
| Bnt | 73 | 8.8 | 15.5 | 75.7 | 70.6 | 1.07 |
| BC | 82 | 9.3 | 15.4 | 75.3 | 70.2 | 1.07 |
| C ₁ | 81 | 8.0 | 13.9 | 78.1 | 72.2 | 1.08 |
| Cca | 79 | 7.9 | 13.0 | 79.1 | 73.3 | 1.08 |
| Classification: Brown Solod | | | | | | |
| Ah | 78 | 9.6 | 16.2 | 74.2 | 70.4 | 1.05 |
| Ahe | 82 | 8.4 | 15.5 | 76.1 | 69.8 | 1.09 |
| Ae | 84 | 8.9 | 15.1 | 76.0 | 70.6 | 1.08 |
| AB | 74 | 8.8 | 14.8 | 76.4 | 70.9 | 1.08 |
| Bnt | 69 | 7.6 | 12.8 | 79.6 | 72.2 | 1.10 |
| C ₁ | 76 | 7.5 | 12.7 | 79.8 | 71.4 | 1.12 |
| C ₂ | 79 | 7.0 | 10.8 | 82.2 | 73.5 | 1.12 |

¹ % K₂O x 5.9

² (% Na₂O x 8.5) + (% CaO x 4.95)

³ 100 - (% Potassium Feldspar + % Soda-Calcic Feldspar)

TABLE XVII. EVALUATION OF PARENT MATERIAL UNIFORMITY (SITE 2)

| | | Fine Sand Fraction | | | Quartz ³ in V.F.S. % | <u>% Quartz in F.S.</u> % Quartz in V.F.S. |
|--|--------------|---|---|--------------------------|---------------------------------------|---|
| | Nonclay % | Potassium ¹ Feldspar % | Soda-Calcic ² Feldspar % | Quartz ³ % | | |
| Hor. | | | | | | |
| Classification: Solodic Dark Brown Chernozem | | | | | | |
| Ahe | 87 | 11.2 | 21.6 | 67.2 | 61.9 | 1.09 |
| AB | 78 | 11.0 | 21.7 | 67.3 | 61.7 | 1.07 |
| Bntj | 78 | 10.2 | 24.3 | 65.5 | 60.2 | 1.09 |
| Bt | 73 | 10.3 | 24.7 | 65.0 | 61.6 | 1.06 |
| Cca | 82 | 11.5 | 23.4 | 65.1 | 61.4 | 1.06 |
| Classification: Eroded Brown Solod | | | | | | |
| Ahe | 84 | 10.7 | 21.3 | 68.0 | 61.9 | 1.10 |
| AB | 77 | 10.5 | 21.7 | 67.8 | 59.8 | 1.13 |
| Bnt | 72 | 11.6 | 22.9 | 65.5 | 59.5 | 1.10 |
| C | 80 | 10.3 | 27.5 | 62.2 | 60.2 | 1.03 |
| Classification: Eroded Brown Solonetz | | | | | | |
| Ae | 87 | 11.7 | 27.3 | 61.0 | 62.8 | 0.97 |
| Bnt | 72 | 11.0 | 26.0 | 63.0 | 61.5 | 1.02 |
| Ccak | 84 | 11.5 | 27.5 | 61.0 | 60.7 | 1.01 |
| Csaca | 83 | 11.0 | 28.3 | 60.7 | 60.5 | 1.00 |

¹ % K₂O x 5.9

² (% Na₂O x 8.5) + (% CaO x 4.95)

³ 100 - (% Potassium Feldspar + % Soda-Calcic Feldspar)

TABLE XVIII. EVALUATION OF PARENT MATERIAL UNIFORMITY (SITE 3)

| Hor. | Nonclay % | Fine Sand Fraction | | | Quartz ³ in V.F.S. % | <u>% Quartz in F.S.</u> <u>% Quartz in V.F.S.</u> |
|------------------------------------|--------------|------------------------|--------------------------|---------------------|---------------------------------------|--|
| | | Potassium ¹ | Soda-Calcic ² | Quartz ³ | | |
| | | Feldspar % | Feldspar % | | | |
| Classification: Brown Solonetz (A) | | | | | | |
| Ah | 83 | 9.4 | 18.1 | 72.5 | 67.5 | 1.07 |
| Ae | 80 | 9.7 | 19.8 | 70.5 | 69.4 | 1.01 |
| Bnt | 70 | 7.1 | 16.8 | 76.1 | 73.6 | 1.03 |
| BCsaca | 73 | 10.2 | 18.7 | 71.1 | 64.2 | 1.11 |
| Csaca | 72 | 9.0 | 15.7 | 75.3 | 69.8 | 1.08 |
| Ck | 73 | 10.6 | 19.1 | 70.3 | 64.7 | 1.09 |
| Classification: Brown Solonetz (B) | | | | | | |
| Ah | 90 | 9.9 | 16.7 | 73.4 | 69.6 | 1.06 |
| Ae | 85 | 9.0 | 17.3 | 73.7 | 67.2 | 1.10 |
| Bnt ₁ | 71 | 10.4 | 17.5 | 72.1 | 64.3 | 1.12 |
| Bnt ₂ | 71 | 10.1 | 18.7 | 71.2 | 65.5 | 1.09 |
| BCsa | 74 | 10.3 | 18.3 | 71.4 | 63.9 | 1.12 |
| Csk | 73 | 10.7 | 18.6 | 70.7 | 65.0 | 1.09 |
| Csca | 80 | 10.9 | 19.5 | 69.6 | 64.8 | 1.08 |

¹ % K₂O x 5.9

² (% Na₂O x 8.5) + (% CaO x 4.95)

³ 100 - (% Potassium Feldspar) + (% Soda-Calcic Feldspar)

percentages in the two fractions points out the constancy of the particle-size distribution of this mineral throughout the profile and thus suggests uniformity of the parent material.

As a supplementary indication of parent material uniformity, the percentages by weight of the nonclay fractions are also shown in Tables XVI to XVIII. These values were obtained by adding together the percentages of sand and silt as determined by mechanical analysis (Tables VIII to X). The nonclay percentage is generally uniform in the BC and C horizons, decreases markedly in the illuvial horizons, and is highest in the eluvial horizon. Consequently, the pedogenic type of clay distribution encountered in all profiles (Tables XVI to XVIII) suggests relative homogeneity of the original material from which the present profiles have formed.

The percentage of the nonclay fraction is preferred to the percentage of the sand fraction as an indicator of the uniformity of the parent material since some disintegration of the nonclay fraction has occurred, as was shown earlier in this discussion (Physical Analyses section).

Moreover, the profiles selected for sampling showed no visible signs of stratification.

(c) Calculation of the net gains and losses of the clay and nonclay fractions occurring in the profiles under study -
According to the method outlined by Barshad (1964) the weight of soil material originally present in any horizon can be calculated on the basis of the present weight of index mineral in this horizon.

The mineral chosen as the index mineral for this study is quartz.

The percentage of quartz in the fine sand fraction is used to calculate the weight of index mineral present in the nonclay fraction of each horizon, based on the assumption that the degree of weathering of the fine sand fraction is indicative of that for the entire nonclay fraction.

A relative increase in concentration of index mineral, especially in the weathered horizons, may be expected as a consequence of negative enrichment which results from the solubilization of less resistant minerals. However, the percentages of quartz in the fine and very fine sand fractions of the Brown Solonetz and Brown Solod at site 1 increases slightly with depth whereas for the profiles of sites 2 and 3 (Tables XVII and XVIII), the quartz percentages in the upper horizons indicate only a slight negative enrichment. The unexpected distribution of quartz at least in part may be explained by the continual disintegration of feldspar-bearing rocks into finer fragments. Disintegration may reduce or offset completely the increase in quartz content that may be expected from negative enrichment through the addition of new feldspar minerals to the finer sand fractions. Gravenor (1954) reported that the products of disintegration of pebbles and boulders are mainly found in the medium and fine sand fractions. These are the size fractions for which quartz percentages were determined.

The soil profiles located at site 1 show a gradual increase in quartz percentage for the fine and very fine sand fractions (Table XVI) with depth. These profiles show the most distinctive evidence for disintegration of coarse material to finer size. The soil profiles located at sites 2 and 3 show a slightly higher percentage of quartz in the upper horizons than in the BC and C horizons.

On the basis of the information available, quartz appeared to be the most suitable index mineral since resistant heavy minerals (zircon and rutile) were found too rare to carry quantitative determinations.

The weight of quartz as an index mineral in the nonclay fraction was therefore calculated for each horizon. It is reasonable to assume that contribution to the sand fraction was at least partially off-set by disintegration of sand size grains to the silt sizes.

Since a loss of index mineral in the weathered horizons may result in lower values for calculated original weight of clay and nonclay material, it became necessary to calculate the net gains and losses of clay and nonclay materials by an alternative method. This method is essentially based on the assumption that the original weight of soil parent material in a given volume presently occupied by a definite horizon is equal to the weight of the underlying parent material that would fill the same volume. The soil volume is determined on the basis of the depth of the horizon and a unit surface area (1 cm.^2). However, this method is expected to be inaccurate for the calculation of the amount of original soil material present in the Ah and Ahe horizons since both horizons may have been thickened through the addition of organic matter. Barshad's index mineral method was therefore retained to calculate the original weight of soil material in the Ah and Ahe horizons despite the possibility of a decrease in content of index mineral through the enrichment of feldspar's.

Although calculations of the weight of the original soil material on the basis of horizon depth does not take into account the

possible depth changes of horizons during pedogeneses, it nevertheless gives the net amount of clay and nonclay gained or lost in the soil volume presently occupied by any particular horizon.

In order to further facilitate the evaluation of profile development, the following assumptions were made:

- (1) The horizon chosen to represent the original parent material has not been modified by pedogenesis and is truly representative of the material from which the soil has developed.
- (2) The soil body has developed from a homogeneous parent material.
- (3) At the outset of pedogenesis, the bulk density was uniform throughout the entire volume presently occupied by the soil sola.

Based on the foregoing premises, it was possible to calculate the net gains and losses of clay and nonclay that have taken place in the soil body. To aid in the understanding of the calculations involved in Tables XIX to XXV, a detailed explanation of each column follows, using the Ah horizon of Table XIX as an example:

Columns 1 and 2. These were obtained directly from Tables XI(a) to XIII.

Column 3. Weight of soil was calculated for a column of soil having 1 cm.² of surface and the depth of the horizon.

eg. Ah horizon: 13 cm. x 1 cm.² x .80 gm./cc. = 10.4 g.

Column 4. Per cent loss was calculated on the basis of the loss of weight resulting from peroxide treatment and salt removal as part of the step involved in mechanical analysis.

eg. Initial weight 10.00 g.
Basic weight 9.37 g.
Loss 0.63 g.
% Loss $\frac{0.63}{10} \times 100 = 6.3\%$

Column 5. Present net weight of soil is calculated by subtracting per cent loss from the weight of soil.

eg. Ah horizon: $\frac{10.4 \text{ g.} \times (100 - 6.3)}{100} = 9.7 \text{ g.}$

Column 6. Present percentage of nonclay in soil is obtained by adding the percentages of sand and silt from Tables VIII to X.

eg. Ah horizon: $30\% + 52\% = 82\%$

Column 7. Per cent of quartz in the fine sand fraction is obtained from Tables XVI to XVIII.

eg. Ah horizon: 74.8%

Column 8. Weight of index mineral is taken as the weight of quartz in the entire nonclay fraction based on the assumption that the percentage of quartz in the fine sand fraction is representative of the percentage of quartz in the entire nonclay fraction.

eg. Ah horizon: $\frac{9.7 \text{ g.} \times 82 \times 74.8}{100 \times 100} = 6.0 \text{ g.}$

Column 9. Present weight of clay is calculated by multiplying the present weight of soil by the total clay percentage given in Tables VIII(a) to X.

eg. Ah horizon: $\frac{9.7 \text{ g.} \times 18}{100} = 1.8 \text{ g.}$

Column 10. Original weight of clay calculated on the basis of index mineral content is determined by relating the weight of clay and index mineral in the parent material of each profile to the weight of index mineral in the horizon under consideration.

eg. Ah horizon: $\frac{4.7 \text{ g.} \times 6.0 \text{ g.}}{14.0 \text{ g.}} = 2.0 \text{ g.}$

Column 11. Original weight of clay based on depth of horizon is calculated by relating the weight of clay and the depth of the parent material to the depth of the horizon under consideration.

eg. Ah horizon:
$$\frac{4.7 \text{ g.} \times 13 \text{ cm.}}{18 \text{ cm.}} = 3.4 \text{ g.}$$

Column 12. Values retained for original weight of clay are reported in columns 10 and 11. Values obtained by the "index mineral" method are retained for the upper horizons (Ah, Ahe) while values obtained from "depth of horizon" method were retained for lower horizons.

Column 13. Net gain or loss of clay is determined by subtracting column 12 from column 9.

eg. Ah horizon: $1.8 \text{ g.} - 2.0 \text{ g.} = -0.2 \text{ g.}$

Column 14. Present weight of nonclay is obtained by subtracting column 9 from column 5.

eg. Ah horizon: $9.7 \text{ g.} - 1.8 \text{ g.} = 7.9 \text{ g.}$

Column 15. Original weight of nonclay based on "index mineral" is calculated by relating the weight of index mineral and nonclay in the parent material to the weight of the index mineral in the other horizons. The original weight of nonclay could also have been calculated by depth of horizon but this was thought unnecessary since only the net gain or loss of clay is considered and no attempt is made to relate the loss of nonclay to the genesis of clay.

eg. Ah horizon:
$$\frac{17.7 \text{ g.} \times 6.0 \text{ g.}}{14.0 \text{ g.}} = 7.5 \text{ g.}$$

Column 16. Gain or loss of nonclay is obtained by the subtraction of column 15 from column 14.

eg. Ah horizon: $7.9 \text{ g.} - 7.5 \text{ g.} = +0.4 \text{ g.}$

TABLE XIX. EVALUATION OF THE NET GAINS AND LOSSES OF THE CLAY AND NONCLAY

| FRACTIONS AT SITE 1 (BROWN SOLONETZ) | | | | | | | | | | |
|--------------------------------------|--|--|--------------------------------|------------------------------|---|--|----------------------------|---------------------------|--|--|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | |
| Hor. and Thickness cm. | Bulk Density g./cc | Wt. of Soil g. | Loss % | Present Wt. of Soil g. | Present Nonclay in Soil % | Quartz in F.S. Fraction % | Wt. of Index Mineral g. | Present Wt. of Clay g. | Original Wt. of Clay; Based on Index Mineral g. | |
| Ah | 13 | 0.80 | 6.3 | 9.7 | 82 | 74.8 | 6.0 | 1.8 | 2.0 | |
| Ahe | 13 | 0.88 | 5.4 | 10.8 | 78 | 74.8 | 7.0 | 1.4 | 2.4 | |
| Ae | 11 | 1.02 | 4.1 | 10.7 | 92 | 74.5 | 7.4 | 0.9 | 2.5 | |
| Bnt | 13 | 1.19 | 6.4 | 14.5 | 73 | 75.7 | 8.0 | 3.9 | 2.7 | |
| BC | 11 | 1.50 | 6.7 | 15.4 | 82 | 75.3 | 9.5 | 2.8 | 3.2 | |
| C1 | 17 | 1.32 | 8.2 | 20.5 | 81 | 78.1 | 13.0 | 3.9 | 4.4 | |
| Cca | 18 | 1.34 | 6.9 | 22.5 | 79 | 79.1 | 14.0 | 4.7 | 4.7 | |
| 1 | 11 | 12 | 13 | 14 | 15 | 16 | | | | |
| Hor. | Original Wt. of Clay; Based on Depth of Horizons g. | Values Retained for Original Wt. of Clay g. | Net Gain or Loss of Clay g. | Present Wt. of Nonclay g. | Calculated Original Wt. of Nonclay* g. | Calculated Gain or Loss of Nonclay g. | | | | |
| Ah | 3.4 | 2.0 | -0.2 | 7.9 | 7.5 | +0.4 | | | | |
| Ahe | 3.4 | 2.4 | -1.0 | 9.6 | 8.9 | +1.3 | | | | |
| Ae | 2.9 | 2.9 | -2.0 | 9.8 | 9.3 | +0.5 | | | | |
| Bnt | 3.4 | 3.4 | +0.5 | 10.6 | 10.1 | +0.5 | | | | |
| BC | 2.9 | 2.9 | -0.1 | 12.6 | 12.0 | +0.6 | | | | |
| C1 | 4.5 | 4.5 | -0.6 | 16.6 | 16.4 | +0.2 | | | | |
| Cca | 4.7 | 4.7 | 0.0 | 17.7 | 17.7 | 0.0 | | | | |

* Based on index mineral

TABLE XX. EVALUATION OF THE NET GAINS AND LOSSES OF THE CLAY AND NONCLAY

FRACTIONS AT SITE 1 (BROWN SOLOD)

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---------------------------|--------------------------|----------------------|-----------|------------------------------|------------------------------------|------------------------------------|----------------------------------|---------------------------------|--|
| Hor. and Thickness cm. | Bulk Density g./cc | Wt. of Soil g. | Loss % | Present Wt. of Soil g. | Present Nonclay in Soil % | Quartz in F.S. Fraction % | Wt. of Index Mineral g. | Present Wt. of Clay g. | Original Wt. of Clay; Based on Index Mineral g. |
| Ah | 8 | 0.88 | 7.0 | 7.8 | 6.5 | 78 | 74.2 | 3.8 | 1.4 |
| Ahe | 9 | 0.88 | 7.9 | 6.2 | 7.4 | 82 | 76.1 | 4.6 | 1.7 |
| Ae | 10 | 1.07 | 10.7 | 2.8 | 10.4 | 84 | 76.0 | 6.6 | 2.4 |
| AB | 6 | 1.18 | 7.1 | 2.3 | 6.9 | 74 | 76.4 | 3.9 | 1.4 |
| Bnt | 14 | 1.27 | 17.8 | 3.6 | 17.2 | 69 | 79.6 | 9.5 | 3.5 |
| C ₁ | 14 | 1.37 | 19.2 | 5.8 | 18.1 | 76 | 79.8 | 11.0 | 4.0 |
| C ₂ | 12 | 1.38 | 16.6 | 3.8 | 16.0 | 77 | 82.2 | 10.1 | 3.7 |

| 1 | 11 | 12 | 13 | 14 | 15 | 16 |
|----------------|--|--|--------------------------------------|---------------------------------|---|--|
| Hor. | Original Wt. of Clay; Based on Depth of Horizons g. | Values Retained for Original Wt. of Clay g. | Net Gain or Loss of Clay g. | Present Wt. of Nonclay g. | Calculated Original Wt. of Nonclay* g. | Calculated Gain or Loss of Nonclay g. |
| Ah | 2.5 | 1.4 | 0.0 | 5.1 | 4.6 | +0.5 |
| Ahe | 2.8 | 1.7 | -0.4 | 6.1 | 5.6 | +0.5 |
| Ae | 3.1 | 3.1 | -1.4 | 8.7 | 8.1 | +0.6 |
| AB | 1.8 | 1.8 | 0.0 | 5.1 | 4.8 | +0.3 |
| Bnt | 4.3 | 4.3 | +1.0 | 11.9 | 11.5 | +0.4 |
| C ₁ | 4.3 | 4.3 | 0.0 | 13.8 | 13.4 | +0.4 |
| C ₂ | 3.7 | 3.7 | 0.0 | 12.3 | 12.3 | 0.0 |

* Based on index mineral

TABLE XXI. EVALUATION OF THE NET GAINS AND LOSSES OF THE CLAY AND NONCLAY

FRACTIONS AT SITE 2 (SOLEDIC DARK BROWN CHERNOZEM)

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|------------------------------|--------------------------|----------------------|-----------|------------------------------|------------------------------------|------------------------------------|----------------------------------|---------------------------------|--|
| Hor. and Thickness cm. | Bulk Density g./cc | Wt. of Soil g. | Loss % | Present Wt. of Soil g. | Present Nonclay in Soil % | Quartz in F.S. Fraction % | Wt. of Index Mineral g. | Present Wt. of Clay g. | Original Wt. of Clay; Based on Index Mineral g. |
| Ahe | 9 | 8.9 | 4.6 | 8.5 | 87 | 67.2 | 5.0 | 1.1 | 1.7 |
| AB | 10 | 11.0 | 5.4 | 10.4 | 78 | 67.3 | 5.5 | 2.3 | 1.8 |
| Bntj | 20 | 24.6 | 5.2 | 23.3 | 78 | 65.5 | 11.9 | 5.1 | 4.0 |
| Bt | 20 | 26.8 | 5.5 | 25.3 | 73 | 65.0 | 12.0 | 6.8 | 4.1 |
| Cca | 29 | 37.1 | 6.3 | 34.8 | 82 | 65.1 | 18.6 | 6.3 | 6.3 |

| 1 | 11 | 12 | 13 | 14 | 15 | 16 |
|------|--|--|--------------------------------------|---------------------------------|---|--|
| Hor. | Original Wt. of Clay; Based on Depth of Horizons g. | Values Retained for Original Wt. of Clay g. | Net Gain or Loss of Clay g. | Present Wt. of Nonclay g. | Calculated Original Wt. of Nonclay* g. | Calculated Gain or Loss of Nonclay g. |
| Ahe | 1.9 | 1.7 | -0.6 | 7.4 | 7.6 | -0.2 |
| AB | 2.2 | 1.8 | +0.5 | 8.1 | 8.4 | -0.3 |
| Bntj | 4.3 | 4.3 | +0.8 | 18.2 | 18.2 | 0.0 |
| Bt | 4.3 | 4.3 | +2.5 | 18.5 | 18.4 | +0.1 |
| Cca | 6.3 | 6.3 | 0.0 | 28.5 | 28.5 | 0.0 |

* Based on index mineral

TABLE XXII. EVALUATION OF THE NET GAINS AND LOSSES OF THE CLAY AND NONCLAY
FRACTIONS AT SITE 2 (ERODED BROWN SOLOID)

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|------------------------------|--------------------------|----------------------|-----------|------------------------------|------------------------------------|------------------------------------|----------------------------------|---------------------------------|--|
| Hor. and Thickness cm. | Bulk Density g./cc | Wt. of Soil g. | Loss % | Present Wt. of Soil g. | Present Nonclay in Soil % | Quartz in F.S. Fraction % | Wt. of Index Mineral g. | Present Wt. of Clay g. | Original Wt. of Clay; Based on Index Mineral g. |
| Ahe | 1.02 | 10.2 | 6.6 | 9.5 | 84 | 68.0 | 5.4 | 1.5 | 2.2 |
| AB | 1.11 | 17.9 | 5.8 | 16.9 | 77 | 67.8 | 8.8 | 3.9 | 3.6 |
| Bnt | 1.27 | 38.1 | 8.1 | 35.0 | 72 | 65.5 | 16.5 | 9.8 | 6.7 |
| C | 1.30 | 14.3 | 5.7 | 13.5 | 80 | 62.2 | 6.7 | 2.7 | 2.7 |

| 1 | 11 | 12 | 13 | 14 | 15 | 16 |
|------|--|--|--------------------------------------|---------------------------------|---|--|
| Hor. | Original Wt. of Clay; Based on Depth of Horizons g. | Values Retained for Original Wt. of Clay g. | Net Gain or Loss of Clay g. | Present Wt. of Nonclay g. | Calculated Original Wt. of Nonclay* g. | Calculated Gain or Loss of Nonclay g. |
| Ahe | 2.5 | 2.2 | -0.7 | 8.0 | 8.8 | -0.8 |
| AB | 3.9 | 3.6 | -0.3 | 13.0 | 14.2 | -1.2 |
| Bnt | 7.4 | 7.4 | +2.4 | 25.2 | 26.5 | -1.3 |
| C | 2.7 | 2.7 | 0.0 | 10.8 | 10.8 | 0.0 |

* Based on index mineral

TABLE XXIII. EVALUATION OF THE NET GAINS AND LOSSES OF THE CLAY AND NONCLAY

| FRACTIONS AT SITE 2 (ERODED BROWN SOLONETZ) | | | | | | | | | | |
|---|--|--|--------------------------------------|----------------------------------|---|--|----------------------------------|---------------------------------|--|--|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | |
| Hor. and Thickness | Bulk Density g./cc | Wt. of Soil g. | Loss % | Present Net Wt. of Soil g. | Present Nonclay in Soil % | Quartz in F.S. Fraction % | Wt. of Index Mineral g. | Present Wt. of Clay g. | Original Wt. of Clay; Based on Index Mineral g. | |
| Ae 6 | .97 | 5.8 | 12.0 | 5.1 | 87 | 61.0 | 2.7 | 0.7 | 0.9 | |
| Bnt 23 | 1.24 | 28.5 | 8.3 | 26.1 | 72 | 63.0 | 11.8 | 7.3 | 3.9 | |
| Ccak 28 | 1.21 | 33.9 | 5.6 | 32.0 | 84 | 61.0 | 16.4 | 5.1 | 5.5 | |
| Csaca 11 | 1.37 | 15.1 | 6.0 | 14.2 | 83 | 60.7 | 7.2 | 2.4 | 2.4 | |
| | | | | | | | | | | |
| 1 | 11 | 12 | 13 | 14 | 15 | 16 | | | | |
| Hor. | Original Wt. of Clay; Based on Depth of Horizons g. | Values Retained for Original Wt. of Clay g. | Net Gain or Loss of Clay g. | Present Wt. of Nonclay g. | Calculated Original Wt. of Nonclay* g. | Calculated Gain or Loss of Nonclay g. | | | | |
| Ae | 1.3 | 0.9 | -0.2 | 4.4 | 4.5 | -0.1 | | | | |
| Bnt | 5.0 | 5.0 | +2.3 | 18.8 | 19.5 | -0.7 | | | | |
| Ccak | 6.1 | 6.1 | -1.0 | 26.9 | 27.1 | -0.2 | | | | |
| Csaca | 2.4 | 2.4 | 0.0 | 11.8 | 11.8 | 0.0 | | | | |

* Based on index mineral

TABLE XXIV. EVALUATION OF THE NET GAINS AND LOSSES OF THE CLAY AND NONCLAY

| FRACTIONS AT SITE 3 (BROWN SOLONETZ (A)) | | | | | | | | | | |
|---|--------------------|----------------|--------|------------------------|---------------------------|---------------------------|-------------------------|------------------------|---|------|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | |
| Hor. and Thickness cm. | Bulk Density g./cc | Wt. of Soil g. | Loss % | Present Wt. of Soil g. | Present Nonclay in Soil % | Quartz in F.S. Fraction % | Wt. of Index Mineral g. | Present Wt. of Clay g. | Original Wt. of Clay; Based on Index Mineral g. | |
| Ah | 10 | 1.04 | 10.4 | 8.2 | 9.6 | 83 | 72.5 | 5.8 | 1.6 | 3.0 |
| Ae | 11 | 1.10 | 12.1 | 5.6 | 11.4 | 80 | 70.5 | 6.4 | 2.3 | 3.4 |
| Bnt | 23 | 1.18 | 27.1 | 6.0 | 25.5 | 70 | 76.1 | 13.6 | 7.7 | 7.2 |
| BCsaca | 18 | 1.22 | 22.0 | 10.6 | 19.6 | 73 | 71.1 | 10.2 | 5.3 | 5.4 |
| Csaca | 34 | 1.37 | 46.6 | 10.6 | 41.6 | 72 | 75.3 | 22.6 | 11.7 | 11.9 |
| Ck | 15 | 1.38 | 20.7 | 16.0 | 17.4 | 73 | 70.3 | 8.9 | 4.7 | 4.7 |

| 1 | 11 | 12 | 13 | 14 | 15 | 16 |
|--------|---|---|-----------------------------|---------------------------|--|---------------------------------------|
| Hor. | Original Wt. of Clay; Based on Depth of Horizons g. | Values Retained for Original Wt. of Clay g. | Net Gain or Loss of Clay g. | Present Wt. of Nonclay g. | Calculated Original Wt. of Nonclay* g. | Calculated Gain or Loss of Nonclay g. |
| Ah | 3.1 | 3.0 | -1.4 | 7.9 | 8.0 | +0.1 |
| Ae | 3.4 | 3.4 | -1.1 | 9.1 | 8.9 | -0.2 |
| Bnt | 7.2 | 7.2 | +0.5 | 17.8 | 18.8 | -1.0 |
| BCsaca | 5.6 | 5.6 | -0.3 | 14.3 | 14.1 | +0.2 |
| Csaca | 10.6 | 10.6 | +1.1 | 29.9 | 31.2 | -1.3 |
| Ck | 4.7 | 4.7 | 0.0 | 12.7 | 12.7 | 0.0 |

* Based on index mineral

TABLE XXV. EVALUATION OF THE NET GAINS AND LOSSES OF THE CLAY AND NONCLAY

| FRACTIONS AT SITE 3 (BROWN SOLONETZ (B)) | | | | | | | | | | |
|---|--------------------|---------------|--------|-----------------------|--------------------|---------------------------|------------------------|-----------------------|--|--|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | |
| Hor. and Thickness cm. | Bulk Density g./cc | Wt.of Soil g. | Loss % | Present Wt.of Soil g. | Present Net Soil % | Quartz in F.S. Fraction % | Wt.of Index Mineral g. | Present Wt.of Clay g. | Original Wt.of Clay; Based on Index Mineral g. | |
| Ah | 9 | 8.1 | 10.2 | 7.3 | 90 | 73.4 | 4.8 | 0.7 | 1.7 | |
| Ae | 10 | 10.2 | 3.9 | 9.8 | 85 | 73.7 | 6.1 | 1.5 | 2.2 | |
| Bnt1 | 10 | 11.4 | 5.4 | 10.8 | 71 | 72.1 | 5.5 | 3.1 | 2.0 | |
| Bnt2 | 12 | 15.7 | 2.8 | 15.3 | 71 | 71.2 | 7.7 | 4.4 | 2.7 | |
| BCsa | 13 | 17.6 | 3.7 | 16.9 | 74 | 71.4 | 8.9 | 4.4 | 3.2 | |
| Csk | 15 | 22.5 | 5.4 | 21.3 | 73 | 70.7 | 10.0 | 5.8 | 3.6 | |
| Csca | 9 | 12.0 | 11.0 | 10.7 | 80 | 69.6 | 5.9 | 2.1 | 2.1 | |

| 1 | 11 | 12 | 13 | 14 | 15 | 16 |
|------|---|---|-----------------------------|---------------------------|--|---------------------------------------|
| Hor. | Original Wt. of Clay; Based on Depth of Horizons g. | Values Retained for Original Wt. of Clay g. | Net Gain or Loss of Clay g. | Present Wt. of Nonclay g. | Calculated Original Wt. of Nonclay* g. | Calculated Gain or Loss of Nonclay g. |
| Ah | 2.1 | 1.7 | -1.0 | 6.5 | 6.9 | -0.4 |
| Ae | 2.4 | 2.4 | -0.9 | 8.3 | 8.8 | -0.5 |
| Bnt1 | 2.4 | 2.4 | +0.7 | 7.7 | 7.9 | -0.2 |
| Bnt2 | 2.8 | 2.8 | +1.6 | 10.9 | 11.1 | -0.2 |
| BCsa | 3.1 | 3.1 | +1.3 | 12.5 | 12.8 | -0.3 |
| Csk | 3.6 | 3.6 | +2.2 | 15.5 | 15.8 | -0.3 |
| Csca | 2.1 | 2.1 | 0.0 | 8.5 | 8.5 | 0.0 |

* Based on index mineral

Several conclusions may be drawn from Tables XIX to XXV.

Firstly, it must be noted that the original weight of clay as calculated by the "depth of horizon" method is consistently larger, for the upper horizons, than the original weight of clay as calculated by the "index mineral" method. This is in agreement with the fact that accumulation of organic matter in the upper horizons has thickened these horizons.

As expected, the eluvial horizons show a net loss of clay. It must be emphasized that the net gains or losses of clay or nonclay (Tables XIX to XXV) are reported on the basis of the soil volume presently occupied by the horizons and thus do not take into account the possible change in depth that may have taken place during solodization.

The illuvial horizon of all profiles studied showed a net gain of clay as expected. However, for the Brown Solonetz at site 1 and the Brown Solonetz (A) at site 3, the amount of clay gained by the illuvial horizon(s) does not account for the total amount of clay lost by the eluviated surface horizon. This indicates the possibility of clay loss through dissolution during pedogenesis. In all the profiles studied except the Brown Solonetz at site 1 and the Brown Solonetz (A) at site 3, the amount of clay gained by the illuvial horizons is larger than the amount lost from the surface horizons. This suggests that either some clay has formed from the weathering of the nonclay fraction or that erosion has truncated the profiles under consideration.

Loss of clay from horizons below the illuvial horizon may be attributable to lithological variability that may be expected in the glacial till parent materials since the possibility of clay weathering below the illuvial horizon is very remote indeed.

The study of net clay gains or losses resulting from solodization suggest that under intense weathering such as that indicated at site 1, solodization may result in a net loss of clay from the profile. Total net gain of clay observed in all profiles at site 2 and in the Brown Solonetz (B) of site 3 indicate that some of the nonclay fraction may have contributed to clay genesis to the extent that a net clay gain may occur despite its continual removal through the solodization processes.

For the evaluation of profile development in Solonetzic soils, the use of "index minerals" is complicated by the fact that alkalization which occurs as an early step in the solonetzic process brings about a relatively high alkalinity; whereas solodization which occurs later on in the same process results in relatively high acidic conditions. Thus, the possible form and direction of mineral genesis and weathering is difficult to predict under these circumstances.

SUMMARY AND CONCLUSIONS

The main objective of this study was to evaluate the effect of the process of solodization upon the transformation and translocation of clay in Solonetzic soils in which are expressed variable degrees of development. All soils sampled at the same site represent different stages of evolution. The Solodic Dark Brown Chernozem of site 2 is believed to have gone through the last stage of the genesis of Solonetzic soils (solodization) and now are acquiring chernozemic characteristics. The Brown Solonetz (B) at site 3 is believed to be more solodized than the Brown Solonetz (A) at the same site.

Evaluation of the net gains and losses of clay for each horizon in the soil profiles under investigation was undertaken. General mechanisms of solodization were also studied through physical, chemical, and mineralogical analyses of the soils. Some of the major conclusions of this study are:

1. The increase in the sand percentage with depth as well as the particle size distribution of the sand fraction as a function of depth indicates that disintegration of coarse material (sand size and coarser) into particles of finer diameter has occurred. Soils developed at sites 1 and 3 show evidence of more severe disintegration than soils developed at site 2.
2. The lowest pH values are encountered in the Ae horizons and/or in the upper B horizons (transitional AB horizons). This suggests that the maximum intensity of pedogenesis may be expected to occur at the point of contact between the eluvial and illuvial horizons. Low pH values generally correlate with high exchange acidity.

3. The electrical conductivity and soluble cations and anions in the soil-water extracts show that within each sampling site the amount of soluble salt extracted from the soil profile decreases with increased solodization.
4. Sulfate is generally the dominant anion present in the soil-water extracts from all soils under study. Exceptions are the soils at site 1 where bicarbonate and chloride account for more than 50 per cent of the extracted anions. Sodium is generally the dominant cation present in the water soluble salts of all soils under study. Exceptions are the Eroded Brown Solonetz at site 2 and the two Brown Solonetz profiles developed at site 3 where magnesium ions make up the major portion of the extracted cations.
5. In most soils under study, the ratios of exchangeable calcium to exchangeable sodium in the illuvial horizons conform to the limit (≤ 10) established by the National Soil Survey Committee (1965) for Solonetzic B horizons. The Solodic Dark Brown Chernozem developed at site 2 has a ratio of exchangeable calcium to exchangeable sodium greater than 10 and therefore is not included in the Solonetzic order. The Brown Solonetz (A) profile developed at site 3 has an illuvial horizon in which the ratio of exchangeable calcium to exchangeable magnesium is greater than 10. However, magnesium accounts for more than 50 per cent of all exchangeable cations. This profile shows marked solonetzic features and could thus be referred to as "magnesium solonetz".
6. Mineralogical analyses indicate that montmorillonite and illite account for more than 50 per cent of the total clay fraction.

X-ray diffractograms and K_2O content indicate preferential translocation of montmorillonite over illite. The fact that the K_2O content of the illuvial horizons is greater than that of the C horizons points out the possibility of illitization. Presence of chlorite-montmorillonite interlayering and/or chloritization is detected in the total clay fraction from the A horizons of the profiles studied.

7. Light mineral analyses of the fine sand fraction largely reflect the variability in the composition of the parent material among the three sites rather than the variability in the intensity of pedogenic development. It is believed that disintegration of feldspar-bearing boulders and pebbles into particles of finer diameter may have reduced or masked completely the negative enrichment in quartz expected to occur in weathered horizons.
8. The B horizons of all soils studied have a relatively higher clay content than the remaining horizons. These illuvial horizons have also the highest percentage of fine clay which is an expression of the preferential translocation of fine clay and/or comminution of coarse clay size to finer clay size as a result of Na dispersion.
9. Calculations of the net gains or losses resulting from pedogenesis reveals that all eluvial horizons show a net loss of clay while illuvial horizons show a net gain of clay. In most profiles, the amount of clay gained by the illuvial horizons is larger than the amount lost from surface horizons. This suggests erosion of surficial horizons and/or clay formation from the nonclay fraction.
10. Evaluation of profile development in Solonchic soils with the aid

of an index mineral is rendered difficult since solonization and solodization result in alkaline and acidic conditions, respectively, and thus influence the predictability of the direction and form of mineral weathering or genesis.

11. On the basis of the investigation conducted it is apparent that genesis, dissolution, transformation, and translocation of clays occur as a result of solonetzic processes. Translocation of clays within the soil sola appear to be most evident. Although the physical breakdown of coarse mineral particles to finer sizes makes it difficult to ascertain the degree of mineral weathering, there, nevertheless, is little doubt that clay genesis occurs in situ as a consequence of mineral dissolution. Transformation of clays is evident from the increase in illite content in the B horizons which results from illitization. Transformation of clay under similar circumstances have been reported elsewhere (Mathieu, 1960) and Arshad (1964).

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